

# **Pulse Productivity:**

## **Physiological Constraints**

J.D.S. Panwar

J.P. Srivastava



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# Pulse Productivity: Physiological Constraints

**J.D.S. Panwar**

Formerly Head  
Division of Plant Physiology  
Indian Agricultural Research Institute  
New Delhi 110 012

*and*

**J.P. Srivastava**

Professor and Head  
Department of Plant Physiology  
Institute of Agricultural Sciences  
Banaras Hindu University  
Varanasi 221 005



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## Preface

**I**MPORTANCE of legumes in human and animal diets and in improving soil health is well-recognized. In developing countries, particularly in India, where vegetarian populace predominates, after cereals, pulses are the second most important component of diet. Generally, pulses are suitably grown under all agroclimatic conditions and soil types. In crop rotation, pulses play a very significant role, as they fix atmospheric nitrogen, solublize insoluble phosphorous in soil, improve soil physical environment, increase soil microbial activity and restore organic matter in soil.

India is the largest producer and consumer of pulses. With increase in area under pulse crops, production has also increased by 28.45% in 2010-11 to 17.29 million tonnes from 14.20 million tonnes in 2006-07. India consumes around 21 million tonnes of pulses a year, therefore, currently about 2-3 million tonnes of pulses are imported annually to meet the domestic requirement. The projected pulse requirement by the year 2030 is estimated at about 32 million tonnes, which requires an annual growth rate of 4.2%. Though the net availability of foodgrains per caput per day has increased from 398.9 g in 1962 to 439.3 g in 2008, the net availability of pulses has reduced from 62.2 g per caput per day in 1962 to 35.5 g per caput per day in 2007 and below 35 g per caput per day in 2011. The area under pulse crops is almost stagnated and in spite of improvement in productivity, the production and consumption gap is increasing. There is a need to increase production and productivity of pulses in our country by more intensive interventions. Pulses with major contribution in national production are chickpea (39%), pigeonpea (21%), *mung* bean (11%), *urd* bean (10%) and lentil (7%). However, field pea, lathyrus, rajmash, cowpea, moth bean, *guar*, and winged bean also contribute substantially under specific agroclimatic conditions.

Average yield of pulses in India is much below than the global averages. Major constraints associated with this crop include, low yield potential, unstable production levels due to biotic and abiotic stresses, and lower responses to environmental manipulation and high inputs. There is a need to analyze growth and yield attributes, identify adaptive morphological, physiological, and biochemical traits associated with stress tolerance and higher productivity under diverse agroclimatic conditions. Under changing climatic conditions, a better understanding of molecular mechanism by which pulses sense and respond to different environmental stresses is also essential.

With these considerations, authors have tried to incorporate chapters on production and productivity scenario, canopy and root development, biological nitrogen fixation, physiology of growth and yield components, light and water-use efficiency, physiological aspects of pulse-cereal intercropping and nutritional qualities concerned with all major and minor pulses, viz. chickpea, pigeonpea, MULLaRP , and arid legumes (cowpea, moth bean, *guar*, winged bean), grown in different agro-ecological regions of India. A brief botany, origin and economic uses have also been covered. Chapters on ideal plant type as well as molecular basis to face challenges in pulse production are also incorporated. In the light of global climate change, a chapter on effect of greenhouse gases and global warming in pulses has been specifically included in this book.

The book will fulfill the growing needs of all students and researchers of agricultural sciences in general, and of crop physiology in particular, concerned with pulses in Indian context.

Authors are thankful to the reviewers of the manuscript for their critical comments to improve the quality of the book, and to the Indian Council of Agricultural Research, New Delhi, for providing financial assistance to complete this manuscript.

New Delhi

J.D.S. Panwar

J.P. Srivastava



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# **CHAPTER 1**

## **Introduction**

**I**ndia has achieved self-sufficiency in food production through increased productivity (green revolution), particularly in cereal crops. India is the largest producer as well as consumer of pulses, where production lags behind the consumption. We have to spent a lot of foreign reserves to meet the demand, since we import considerable quantity of pulses from different countries, viz. Australia, Canada, Myanmar, Brazil, etc. Major pulses which are being imported are peas, chickpea, pigeonpea, mung, dry beans, lentil, kidney bean, *urd* bean, and broad beans. Pulses are important source of proteins and make a balanced vegetarian diet when consumed with cereals. Pulses normally contain 20-25% proteins on dry-weight basis, which is almost 2.5-3.0 times higher than that of cereals. When eaten with cereals, pulses provide a perfect mix of high biological value. Pulses have the unique quality to fix atmospheric nitrogen and, therefore, they help in improving the soil health. Pulses also help in solubilizing insoluble phosphorus in the soil, improve soil physical environment, increase soil microbial activity and restore organic matter in the soil. Therefore, pulses not only increase the yield of the companion crop, but also spare nitrogen for the succeeding crop in various intercropping systems. Pulses are also cultivated for green manuring. They have deep root system and, therefore, are able to trap the moisture and nutrients from the deeper strata of the soil, and fits well under rainfed conditions (Ghosh *et al.*, 2007).

Keeping into consideration the importance of these crops under Indian condition, Government of India has taken various steps time to time to increase the productivity and production of pulses in the country. All India Coordinated Research Project on Pulses (AICRPP) was started to conduct coordinated research in all the nine pulse crops, viz. chickpea, pigeonpea, pea, mungbean, urd bean, lentil, cowpea, lathyrus, and rajmash. The efforts are being made for varietal improvement, integrated nutrient management, cropping system, host plant resistance, integrated pest and disease management, biological nitrogen fixation, drought tolerance, and other crop specific and region specific research. In frontline demonstrations, this effort has registered 15-25% improvement in the yield. In the Eight Five-Year Plan, National Pulse Development Project (NPDP) was initiated and then Technology Mission on Oilseed and Pulses (TMOP) was initiation in 1990 for better implementation of the

programme. In Tenth Five-Year Plan, it was proposed to implement the Integrated Scheme of Oilseed, Pulses, Oil palm and Maize (ISOPOM), to make the programme more integrated and financially sound (Anonymous, 2004), with major emphasis on seed production, distribution and adoption of improved technology. In Eleventh Five-Year Plan (2008-2012), National Food Security Mission (NFSM) was launched targeting important food grain crops, rice, wheat and pulses. The main objective of this mission is to increase production of pulses by 2 million tonnes through increase in area and productivity by adopting the improved varieties and proven crop production and protection technologies. Recently, Government of India has earmarked ‘ 300 crore for organizing 60,000 pulses and oilseed, seed villages in rainfed area under Rastriya Krishi Vikas Yojna (RKVY), and are planning to undertake pulse production over one million hectare of land with 4.4 million tonnes more production during the remaining period of current plan period, i.e. by the end of 2012.

In spite of several efforts the production of pulses has remained virtually stagnant for the last 40 years (539 kg/ha in 1961 to 544 kg/ha in 2001 and 617 kg/ha in 2009). In the recent past, production of pulses has increased due to the expansion of area of *rabi* pulses and a shift in pulse production area from Northern India to Central and Southern part of the country. The yield level of *kharif* pulses (417 kg/ha to 557 kg/ha) is lower than the yield level of *rabi* pulses (684 kg/ha to 751 kg/ha). It is to be noted that the *rabi* pulses such as chickpea, lentil and urd bean, and long duration pigeonpea that mature with the increasing day length and increasing temperature have higher potential for expanding the pulse production area. Still there is scope for enhancing yield of *rabi* pulses like lentil, dry pea and dry beans, as their average yield of 791, 1000 and 447 kg/ha is much lower than their global averages of 938, 1830 and 705 kg/ha, respectively.

There are two main focuses that need attention, viz. (a) bringing additional area under pulses, and (b) improving crop productivity. If these issues are addressed properly then these may have substantial increase in the pulse production in the country.

Some such new niches for different pulses in various parts of the country are given in Table 1.



**Table 1.** New niches for pulse production in various parts of India

Crop	New niches	Potential area by 2020 (m ha)
Chickpea	Uttar Pradesh, Bihar, West Bengal and Coastal Odisha	0.5
Pigeonpea (early)	North West Rajasthan, Haryana, Punjab, Uttar Pradesh	1.0
Pigeonpea ( <i>rabi</i> )	Bihar, Odisha, Southern Gujarat, Madhya Pradesh, West Bengal, Eastern Uttar Pradesh	0.3
Mungbean (summer)	Punjab, Haryana, Uttar Pradesh, Bihar, West Bengal	1.0
Urd bean ( <i>rabi</i> )	Andhra Pradesh, Karnataka, Tamil Nadu	1.0
Lentil	Eastern Uttar Pradesh, Bihar, Bindelkhand Region	0.5
Lathyrus	Eastern Uttar Pradesh, North Bihar, West Bengal, Chhatisgarh, Bundelkhand region of Uttar Pradesh	0.2
Rajmash	Central and Eastern Uttar Pradesh, Bihar, Maharashtra	0.5
Total		5.0 m ha

Source: Ali, 2004a

The area can be enhanced in various states by growing sole crop or by introduction of pulse crops in different cropping systems. There is a need to improve the traits those can fit well in the intercropping system, like reduction in duration (pigeonpea), plant morphology, adaptation to diverse agroclimatic condition, and competitiveness in terms of productivity in different cropping systems (Ahlawat and Shivkumar, 2005; Ali et al., 2007). As catch crop during summer/spring should have high yielding varieties with early vigour, early and synchronous maturity, responsiveness to high input and resistance to disease and pests prevailing in that area (Ali, 2007). Development of extra short duration varieties with high productivity on per day/unit basis can be fitted with matching technology for growing them in non-traditional areas. The matching of crop phenology, with moisture availability, coupled with disease and pest resistance, will be most essential for successful introduction of pulses in non-traditional areas. Since expansion of area may be limited in different states, efforts should be made to enhance yield potential of these crops under different agro-ecological conditions.

IMPROVING CROP PRODUCTIVITY

Increasing productivity of pulse crop is a challenge for scientists and researchers working in different disciplines like crop physiology, microbiology, biotechnology, agronomy, soil science and plant breeding, etc. They will have to work jointly in a very systematic manner to solve the problems and to achieve the goal. The role of crop physiologists

becomes more challenging particularly under the situation of global climatic changes.

### Physiological Manipulations

The pulse crops are known to be photo-thermo sensitive with indeterminate habit, non synchronous growth, poor pod setting and pre-harvest sprout with poor harvest index. Efforts should be made to develop plant type that can yield better under different agro-climatic conditions, and to tailor the different useful traits for specific plant type for higher productivity. The plants should have high photosynthetic rate with high light use efficiency and better translocation of assimilates towards developing grains. The leaf area duration should be more with high RuBPCO activity during grain development. Enzymes for breaking down the large non transportable carbohydrates into smaller units for better translocation of sugars from leaves and other structural parts to the developing sink, i.e. grain (source-sink relationship) should be more. The plants should also have deeper root system with higher water-use efficiency and should respond to life saving irrigation and fertilization with nitrogen, zinc, molybdenum, and sulphur nutrients application. The yield may be considered on per day basis as early maturing types can be fitted as the catch crop along with a balance of biomass production and high harvest index. The role of plant physiologists becomes even more challenging under the situation of global climatic change which may cause unpredicted variation in rainfall pattern leading to unpredicted drought or waterlogging, wide fluctuations in minimum and maximum temperatures, and other biotic and abiotic calamities that may coincide with different growth and development stages of the plants. They will also have to keep in mind that plant type may differ with change in the target environment, cropping system, and other management practices of the local area.

### Microbial Manipulations

Microbiologists have to play an important role keeping in view that pulse crops have the capacity to fix environmental nitrogen. Pulses, if incorporated in the cropping system save upto 50% of the nitrogen requirements through *Rhizobium*-legume interaction. The efficient *Rhizobium* strain can help for better nodulation and nitrogen fixation ability. The use of phosphorus solubilizing bacteria (PSB), such as, *Bacillus spp.*, has been found to enhance the phosphorus uptake, and when combined with *Rhizobium* had shown the synergistic effect on biomass production and seed yield (Panwar and Thakur 1997; Thakur and Panwar 1997) and with different micronutrients also (Jain *et al.*, 2007a; 2008; 2009). For phosphorus and other micro nutrient uptake, the VAM (*Vesicular Arbuscular Mycorrhiza* fungi) has been reported to increase availability of plant nutrients and water both, thus proved to be the most precious in rainfed agriculture (Panwar and Thakur, 1997). It is imperative



to develop appropriate technology to exploit such naturally occurring soil microorganism and to generate in depth information on their synergies. The use of plant growth promoting rhizobacteria (PGPR) has been found beneficial for enhancing crop productivity (Panwar and Swarnalakshmi, 2005). Research should also be under taken to enhance the shelf life of the *Rhizobium* through liquid based *Rhizobium* culture instead of charcoal based cultures.

Manipulation of Untapped Genes

Wild species have the potential to show the resistance against cyst nematode, drought tolerance, and cold tolerance in chickpea, resistance to mung yellow moisac virus and bruchid in *Vigna*, and can be used for male sterility in pigeonpea. In addition to the tolerance against biotic and abiotic stress, they have genes that are also responsible for high seed yield in inter-specific hybrid (*Cicer arietinum* × *C. reticulatum*) having resistance to cyst nematode. Genes for cold tolerance with the help of biotechnological tools, (*C. reticulatum* × *C. achinospermum*) may also be incorporated. In pigeonpea, some wild species are having specific characteristics, as listed in Table 2, which can be exploited in pigeonpea improvement programme.

Table 2. Significant traits associated with some wild species of pigeonpea

Wild species	Characteristics
<i>Cajanus scarabacoides</i>	Physical and antibiosis types to pod borer
<i>C. sericeus</i>	Rich in protein
<i>C. albicans</i>	Rich in protein, tolerant to soil salinity
<i>C. cajanifolius</i>	Resistance to phytophthora blight

Wild *Vigna* spp. such as *V. trilobata*, *V. grandis*, *V. dalzalliana*, *V. vexillata*, *V. radiata* var. sublobata and *V. mungo* var. silvestris have been used to transfer specific genes for pest and disease resistance and edaphic stresses in the cultivated types. Crosses between mungbean x urd bean resulted in the resistance to MYMV and *Cercospora* leaf spot, synchronous maturity, resistance to shattering and high methionine content in urdbean, and erect growth habit and more seeds per pod in mungbean. Segregating generation of Pant mung 2 × AMP 36 (a variety of urd bean) had shown a wide range of variation for plant type and other agronomic traits. Several progenies were isolated, and it was reported that it was possible to transfer more seeds per pod of mungbean to urd bean; Pant mung 4, developed by crosses made between mungbean and urd bean (Type-44 × UPU-2), is having improved plant type and tolerance to biotic and abiotic stresses (Ali, 2004b). However, interspecific hybridization is successful only when mungbean is used as female parent.



In chickpea, there is a need to develop varieties having resistance against *Fusarium* wilt, root rot, ascochyta and botrytis gray mold, whereas in pigeonpea for stable performance varieties with resistance against wilt, phytophthora stem blight, sterility mosaic are important. In lentil and field pea, resistance to rust, wilt and powdery mildew resistance are important.

### *Hybrid Vigour*

Hybrid development in pigeonpea has paved the way for enhancing crop productivity, recently two stable cytoplasmic sterile lines GT 288A and 67A were developed using cytoplasm of wild species *Cajanus scarabacoides* and *C. sericeus*. The first CMS based pigeonpea hybrid, GTH-1 has been released from Gujarat and it gave 32% higher yield over the best checks. It has white large seeds and matures in 140 days with better yielding potential. In 2008a CMS based hybrid ICPH 2671 was developed, which has given 28 q/ha grain yield. Three new hybrids have been put on trial on farmer's field in collaboration with State Agricultural Universities of Karnataka, Andhra Pradesh and Maharashtra, and will be available for commercialization for multiplication by the end of 2010 (Gowda, 2010). These varieties are ideally suitable for dry land, and are highly resistant to *Fusarium* wilt and sterility mosaic.

### **Agronomic Management**

Agronomic researches have paved the way through using N as starter dose @ 10-15 kg/ha, which is utilized by the plants for early growth till the plant becomes self sufficient for N availability through biological nitrogen fixation. The seed treatment with *Rhizobium* and PSB or VAM fungi has proved beneficial for supplying N, P and Cu, Zn, Mn and Fe and sulphur to the plants (Jain, 2004; Jain *et al.*, 2007b). The application of Zn, phosphorus, boron, sulphur along with *Rhizobium* has positive results for enhancing crop productivity in different pulse crops (Jain *et al.* 2009; Madhu, 2010). The foliar spray of 2% urea at early flowering and pod filling stages has been observed beneficial for higher yield. The sowing of pigeonpea on ridges has given yield advantage over flat sowing and has been recommended to adoption. The use of pre soaked seeds has been proved for better germination and plant stand in the drought prone area (Harris and Kumar Rao, 2008). Water harvesting can be successfully exploited for enhancing the life saving irrigation at critical stages of growth and development.

Diversification in cropping system is important for enhancing the area and productivity of pulse crops, and it can be achieved by:

- Inclusion of short duration varieties of pulses (mungbean/urdb bean) as catch crop in irrigated areas like Punjab, Haryana, and Western Uttar Pradesh.
- Introduction of pulse crops in new niche including *rabi*-summer cultivation.

- Substitution of existing low yielding crops in the prevailing systems with suitable varieties.
- Incorporation of pulses as intercrop with wide space planted crops and relay crops.

Thus, agronomy plays important role in the diversification of pulses in different cropping system (Ali, 2006).

### Plant Protection Management

*Helicoverpa armigera* is the key pest and damages the pods of pigeonpea and chickpea to a large extent. The integrated pest management includes timely sowing, and intercropping with mustard, barley and linseed in chickpea, and sorghum in pigeonpea, use of trap crop such as African giant marigold, *Vicia sativa*. Use of NPV (Nuclear Polyhedroses Virus) @ 250 LE (larval equivalents)/ha or Bt (*Bacillus thuringiensis*) @ 1-1.5 kg/ha, and fixing of perches @ 20-30 perches/ha to attract insectivorous birds. Chemicals like NSKE (neem seed kernal extract) or *Achook* (a nematicide-insecticide prepared from neem) @ 1.25 l/ha or use of neem based chemical, endosulfan is recommended at an interval of 10-20 days after flowering and pod development stages.

Demonstration at farmer's field is also an effective way to impress upon the farmers for technological advancement linked enhanced pulse production. This will not only educate the farmers for adoption of new technology, but also help in enhancing the seed replacement rate of the new varieties or hybrids for better yield per unit area per unit time.

### REFERENCES

- Ahlawat, I. P. S. and Shivkumar, B. G. 2005. Cropping system research in pigeonpea. *In: Advances in Pigeonpea Research*. Ali M. and Shivkumar (Eds). IIPR, Kanpur, pp. 164-181.
- Ali, B.; Hayat, S. and Ahmad, A. 2007. 28-Homo-brassinolide ameliorates saline stress in chickpea. *Environ. Exp. Bot.* **59**: 217-23.
- Ali, M. 2004a. Pulse research and development in India: An overview. *Agriwatch*. **3**: 79-83.
- Ali, M. 2004b. Augmentation of pulses production. *In: Towards National Nutritional Security*. pp. 9-21. <http://ncw.nic.in/pdfreports/towards%20national%20nutritional%20security.pdf>
- Ali, M. 2006. Role of pulses in crop diversification. *In: National Symposium on Conservation Agriculture and Environment*, pp. 363-65.
- Ghosh, P. K.; Bandypadhyay, K. K.; Wanjari, R. H.; Manna, M. C.; Mishra, A. K. and Mohanty, M. 2007. Legume effect for enhancing productivity and nutrient use efficiency in major cropping systems: An Indian perspective-A Review. *J. Sustain Agric.* **30**: 61-86.



- Gowda, C. L. L. 2010. More hybrids varieties of tur to hit market. ICRISAT, 28 July 2010 Business Standard. <http://www.CGIAR.org/enews/April2010>
- Harris, D. and Kumar Rao, J. V. D. K. 2008. Rainfed rabi cropping in rice fallows-chickpea in Eastern India. A development brief prepared by the Centre for Arid Zone Studies, University of Wales, UK; Catholic Relief Sciences, India, Gramin Vikas Trust India, ICRISAT, India. pp 1-7.
- Jain, A. K. 2004. 'Influence of *Rhizobium* inoculation and application of phosphorus and micronutrient on yield, nodulation and seed quality of greengram.' Ph. D. Thesis, Meerut University, Meerut.
- Jain, A. K.; Kumar, S.; Singh, O. P.; Panwar, J. D. S. and Vinod Kumar. 2008. Studies in relation to rhizobium and VAM , inoculation to green gram. *Plant Archieves*. **8**: 935-36.
- Jain, A. K.; Panwar, J. D. S. and Sudhir Kumar. 2009. Plant growth promoting *Rhizobacteria* in crop plants against pests and diseases. *In: Plant Disease Management for Sustainable Agriculture*. Sabid Ahmed, (Ed). Daya Publishing House, New Delhi, pp. 299-327.
- Jain, A. K.; Sudhir Kumar and Panwar, J. D. S. 2007a. Studies on *Rhizobium* with phosphorus and micronutrients on mungbean (*Vigna radiata* L. Wilczek.). *Advances Plant Sci.* **20**(II): 373-76.
- Jain, A. K.; Sudhir Kumar and Panwar, J. D. S. 2007b. Response of mungbean to phosphorus and micronutrients on N and P uptake and seed quality. *Legume Res.* **30**: 201-204.
- Madhu Malik. 2010. 'Effect of plant growth promoting *Rhizobacteria* (PGPR) and micronutrients on pigeonpea (*Cajanus cajan* (L.) Millsp) in relation to nodulation and grain yield.' Ph. D. Thesis, CCS University, Meerut, India.
- Panwar, J. D. S. and Swarnalakshmi, K. 2005. P G P R - A group of biofertilizers for sustainable crop productivity. *In: Development in Physiology, Biochemistry and Molecular Biology of Plants*. Bose B. and Hemantaranjan A. (Eds). New India Publishing Agency, New Delhi, pp. 159-80.
- Panwar, J. D. S. and Thakur, A. K. 1997. Mycorrhizae: Biofertilizers for the future. *Proceedings Third National Conference on Mycorrhiza*, Organized by Tata Energy Research Institute (TERI) at CCHAU, Hisar, pp. 471-77.
- Thakur, A. K. and Panwar, J. D. S. 1997. Response of *Rhizobium- vasicular arbuscular mycorrhizal* symbionts on photosynthesis, nitrogen metabolism and sucrose translocation in green gram (*Phaseolus radiatus*). *Indian J. Agric. Sci.* **67**: 245-48. ●



## **CHAPTER 2**

# **Area, Production and Productivity of Pulses in India**

**I**n India, large population is vegetarian and pulses are the chief source of protein in their diets. The pulse crops play a very important role in maintaining the soil health and, thus, are known to be as a natural mini nitrogen manufacturing factory in the field by virtue of their capacity to fix atmospheric nitrogen symbiotically. Legumes fix atmospheric nitrogen and also help to solubilize P in the soil, improve the soil physical environment, increase soil microbial activity and restore organic matter. Pulses also have smothering effect on weeds. Because of tap root system, pulses help in improving soil aeration. Leaf dropping increases the soil organic matter. Most of the pulses trap moisture from the lower strata of the soil and, therefore, are treated as drought tolerant crops that fit well in rainfed environment (Ghosh *et al.*, 2007).

Over the years, India continues to be the largest producer and consumer of the pulses in the world. Pulses are grown in the Asian countries, including India, Myanmar, Brazil, Pakistan, Canada, Australia, Turkey, USA and Tanzania. Though India is the large producer of major pulses, even then there is a gap between production and consumption and the country is importing a considerable quantity of different pulses. India has imported pulses to a magnitude of 2.04 million tonnes in 2006-07, 1.67 million tonnes in 2007-08, 2.85 million tonnes in 2008-09 and 3.42 million tonnes in 2009-10. During 2010-11 import has decreased by 14.28%, and is estimated to be 3.0 million tonnes. During 2010-11 pulse production in the country has been 17.29 million tonnes, which is the highest ever production record due to significant improvement in production of pulses, particularly of pigeonpea (3.2 million tonnes), *urd* bean (1.832 million tonnes), and mungbean (1.432 million tonnes) Anonymous, 2011a; 2011b. India is importing pulses from Myanmar (27%), Australia (2% *desi* chickpea) and USA 6%. The pigeonpea and *urd* are being imported from Myanmar, Ghana, Kenya, Tanzania and Mozambique. In 2010-11 the import is estimated to be 3.0 million tonnes due to significant improvement in production (Table 1).

**Table 1.** Gap between production and demand, and amount of pulses imported since 2006-07 in country

Year	Production (million tonnes)	Domestic demand (million tonnes)	Gap (million tonnes)
2006-07	14.20	16.24	2.04
2007-08	15.10	16.77	1.67
2008-09	14.66	17.51	2.85
2009-10	14.76	18.28	3.42
2010-11	17.29	20.29	3.00

Source: Anonymous (2009a; 2011a; 2011b)

Area under pulse production, productivity of rabi and kharif pulses from 2000-01 to 2008-09, and its import and export in India are depicted in Table 2.

**Table 2.** Area under pulse production, productivity of *rabi* and *kharif* pulses from 2000-01 to 2008-09, and the status of their import and export.

Year	<i>Kharif</i>			<i>Rabi</i>			Total		
	Area (m ha)	Production (mt)	Productivity (kg/ha)	Area (m ha)	Production (mt)	Productivity (kg/ha)	Area (m ha)	Production (mt)	Productivity (kg/ha)
2000-01	10.7	4.5	417	9.7	6.6	684	20.4	11.1	544
2001-02	10.7	4.8	453	10.9	8.5	762	21.7	13.4	609
2002-03	10.0	4.2	417	10.6	7.0	661	20.5	11.1	543
2003-04	11.7	6.2	528	11.8	8.7	745	23.4	14.9	637
2004-05	11.3	4.7	417	11.4	8.4	735	22.8	13.1	577
2005-06	10.6	4.7	439	11.8	8.5	716	22.4	13.1	585
2006-07	10.7	4.8	449	12.5	9.4	751	23.2	14.2	612
2007-08	11.5	6.4	557	12.1	8.4	709	23.6	14.8	688
2008-09	10.4	5.0	484	12.6	9.2	726	23.0	14.2	617
	Import (MT)			Export (MT)			Total consumption (MT)		
2000-01	0.4			0.2			11.2		
2001-02	2.2			0.2			15.4		
2002-03	2.0			0.2			13.0		
2003-04	1.7			0.2			16.5		
2004-05	1.3			0.3			14.2		
2005-06	1.6			0.4			14.3		
2006-07	3.7			0.4			17.5		
2007-08	2.8			0.2			17.4		
2008-09	2.3			0.1			16.4		

Source: Anonymous (2012)



The Government of India is trying hard to enhance the productivity of pulses by implementing of NSFM on pulses in 16 major pulse-growing states of the country (Anonymous, 2010). The Government of India has earmarked ₹ 300 crores for developing 60 thousand *seed-villages* for pulses and oilseeds, in rainfed areas under Rastriya Krishi Vikas Yojna (RKVY) during the financial year 2010-11. It is also planned to undertake pulse production over one million hectare of land with 4.4 million tonnes higher production during the remaining period of current 11<sup>th</sup> Five-Year plan period that ends in 2012.

The main pulse crops grown in India are chickpea (*desi* chana and *kabuli* chana), red gram or pigeonpea, mungbean, urd bean, lentil, lathyrus, rajmash and field pea. To boost production of pulses, India has developed lots of scientific techniques that could help in improving the crop yield. Indian Council of Agricultural Research (ICAR) is encouraging Indian Institute of Pulse Research, Kanpur, to strengthen the research on basic and applied aspects for improvement of pulse production. Other institutions viz., Indian Agricultural Research Institute, New Delhi, and Agricultural Universities in different states are also involved directly in this effort through the All India Coordinated Research Projects such as AICRP on chickpea, pigeonpea and MULLaRP (mungbean, urd bean, lentil, lathyrus, rajmash and field pea). Additionally, researches on arid legumes are being taken up at Central Arid Zone Research Institute, Jodhpur, under AICRP on Arid Legumes.

During 2010-11 among the major pulse crops, chickpea had its share of 39% of the total pulse production followed by pigeonpea (21%), mungbean (11%), urd bean (10%), lentil (7%) and field pea (5%) (Anonymous, 2011c), while area wise these crops covered 39% (chickpea), 21% (pigeonpea), 11% (mungbean), 10% (urd bean), 7% (lentil) and 5% (field peas).

### MAJOR PULSE-PRODUCING STATES IN INDIA

A list of major pulse producing states in India, and their relative share to national pulse production is given in Table 3. Maharashtra, Madhya Pradesh, Rajasthan, Uttar Pradesh and Andhra Pradesh are major pulse producing states of the country, collectively contributing to about 70% to the national pulse production.

Currently, average national pulse productivity is about 659 kg/ha, but Maharashtra, Chhattisgarh, Odisha, Rajasthan and Karnataka have productivity lesser than the national average.

The major pigeonpea-growing states are Madhya Pradesh, Uttar Pradesh, Bihar, Maharashtra, Karnataka, Andhra Pradesh, Haryana and Gujarat. In Uttar Pradesh, Bihar and Madhya Pradesh, predominantly long duration pigeonpea is grown, while in other states of the country medium or short duration pigeonpea are cultivated. Chickpea is grown in Madhya Pradesh, Rajasthan, Uttar Pradesh and Haryana, whereas major lentil-



**Table 3.** Major pulse producing states in India, and their relative contribution to national pulse production

State	Share to national pulse production (%)
Maharashtra	20
Madhya Pradesh	17
Rajasthan	11
Uttar Pradesh	11
Andhra Pradesh	11
Current production	17.29 million tonnes
By 2020	22.24 million tonnes
Productivity	659 kg/ha
Import	3-4 million tones/year

Source: Anonymous (2010; 2011a; 2011b)

growing states are Madhya Pradesh, Uttar Pradesh and Bihar. Mungbean is grown in *rabi* as well as in *kharif*, and major mungbean-growing states are Maharashtra, Rajasthan, Andhra Pradesh, Karnataka and Bihar. *Urd* bean is cultivated in *kharif* in Rajasthan, Maharashtra, Andhra Pradesh, Karnataka, West Bengal and Odisha. There is a shift of pulses production from north to south; particularly Andhra Pradesh and Karnataka are now having high productivity.

IMPORT AND EXPORTS OF PULSES

In spite of being the largest producer of pulses, India has to import pulses from different countries to meet the domestic requirement. Though the average yield (kg/ha) of pulses has increased, every year nearly 25-30 lakh tonnes of pulses, i.e. equal to 20% of the total domestic production, is being imported. India accounts for 30-40% of the total world imports from countries like Australia, USA, Myanmar, Turkey, Tanzania and Canada. India is providing incentives to import more pulses through introducing low import tariffs.

India is also exporting small quantity of pulses to different countries, viz. Bangladesh, Sri Lanka, Nepal and other SAARC countries, and to UAE, USA, Saudi Arabia, Kuwait and UK.

Availability of Cereals and Pulses in India

Per capita availability of cereals and pulses in India since 1962 are depicted in Table 4.

**Table 4.** Population and availability of foodgrains per capita/day in India

Year	Population (million)	Availability (g per capita per day)		
		Cereals	Pulses	Total
1962	452.2	398.9	62.2	460.9
1972	563.9	419.1	47.0	466.1
1982	703.8	415.6	39.2	454.8
1992	867.8	434.5	34.3	468.8
2002	1,050.6	458.7	35.4	494.1
2003	1,068.2	408.5	29.1	437.6
2004	1,085.6	426.9	35.8	462.7
2005	1,102.8	390.9	31.5	422.4
2006	1,119.8	412.8	32.5	445.3
2007	1,136.5	407.4	35.5	442.8

Source: Ministry of Commerce, Govt. of India

Though the net availability of foodgrains per capita per day has increased from 398.9 g in 1962 to 439.3 g in 2008, the net availability of pulses has reduced from 62.2 g per capita per day in 1962 to 35.5 g per capita per day in 2007 and below 35 g per capita per day in 2011 (Anonymous, 2011c). Self-sufficiency in foodgrain production in India in late 1960s and during 1970s was attributed to increased productivity. The per capita consumption of pulses has declined from the peak of 27.3 kg per year in 1958-59 to the current level of 12.7 kg per year, reflecting a negative CAGR of -1.58%, indicating that availability of pulses hardly kept pace with growing population (Anonymous, 2011c).

The area under food grain production has experienced a decline during 1990s, while area under major commercial crops has witnessed a rise. Although the Government of India has encouraged the shift towards production of commercial crops for enhancing the economic condition and diversity of export basket, nevertheless, such situation may lead to a threat to food security in the country.

The area under pulse crops is almost stagnated and in spite of the increased productivity, the production and consumption gap is increasing. Strong and immediate actions are required to enhance production and productivity of pulses in the country.

## REFERENCES

- Anonymous. 2010. Paper Circulated during Chief Ministers Conference, Government of India, on 6<sup>th</sup> Feb. 2010.
- Anonymous. 2011a. Pulse import likely to dip 14% on higher output. April 28, 2011. <http://business-standard.com/india/news/pulse-import-likely-to>

Anonymous. 2011b. Record foodgrains output of 235.88 mn tonnes in 2010-11: Sharad. PTI, April 6, 2011. [Http://articles.economictimes.indiatimes.com/2011-04-06/news/29388](http://articles.economictimes.indiatimes.com/2011-04-06/news/29388)

Anonymous. 2011c. Shortfall in pulses output to pressure food prices: ASSOCHAM. Export Import News.  
<http://www.infodriveindia.com/userControls/Export-Import-News/shor>

Anonymous. 2009. Department of Agriculture and Coop. Govt of India. 2009.

Ghosh, PK.; Bandyopadhyay, KK.; Wanjari, RH.; Manna, MC.; Mishra, AK. and Mohanty, M. 2007. Legume effect for enhancing productivity and nutrient use efficiency in major cropping systems: An Indian perspective-A Review. *J. Sustain Agric.* **30**: 61-86.



## CHAPTER 3

# Plant Canopy Development and Root Architecture in Pulses

In pulses, the mode of germination depends upon the species concerned. During *rabi*, seeds are placed deep in the soil under limited moisture condition, where as in *kharif* sowings are done when there is no limitation of moisture. In pulses, seed germination is epigeal as well as hypogeal.

Pulses with 22 chromosome number generally show epigeal germination, but rice bean and pigeonpea are the exceptions (22 chromosome number) and have hypogeal germination and sown in *kharif*. Pulses with chromosome number 14 or 16 are sown in *rabi* and show hypogeal germination. The advantage of hypogeal germination over epigeal germination is that chances of damage of former are lesser by the insect pests or by grazing animals. The lateral branches develop from the hypocotylar region at the point of attachment of cotyledons and connect the seed and growing plant. Where as in epigeal germination the hypocotyl is quite important which forms a loop and push up the cotyledon above the soil surface.

### GROWTH AND CANOPY DEVELOPMENT

The leaf area development is quite important and depends upon the species, genotypes and climatic factors. As compared to sorghum and maize, the rate of leaf area development is slower in pulses. A comparison of leaf area developed in one month old pigeonpea, cowpea and sorghum in a single plant and one m<sup>2</sup> canopy levels are depicted in Table 1.

**Table 1.** Leaf area (cm<sup>2</sup>) in one-month-old pigeonpea, cowpea and sorghum crops in a single plant and one m<sup>2</sup> canopy level.

Crop	Single plant (cm <sup>2</sup> )	Canopy of one m <sup>2</sup>
Pigeonpea	46.5	1395
Cowpea	67.0	1612
Sorghum	2707.0	14376

Source: Baldev *et al.*, 1988

The rate of leaf area development is much slower in pigeonpea and cowpea than in sorghum. In sorghum leaf area development starts taking lead since the very early stage after germination. While at germination, sorghum seedlings have 3 or more embryonic leaves, which start developing immediately after germination, whereas in pulses initially two leaves emerge and subsequently leaf emergence is slower. The rate of leaf expansion is also faster in sorghum than in pulses.

In pulses initially two important sinks develop, i.e. (i) vegetative shoot, and (ii) root and nodules. Nodules develop in roots after germination, which require additional energy for their growth. These nodules later on contribute towards nitrogen requirement of plants through nitrogen fixation. The leaf area development has direct effect on dry matter production and yield. Genotypic differences have been reported with respect to these parameters. In mungbean genotypes PS16, S9, and S8 are reported to have higher leaf area, biomass production, and grain yield as compared to genotypes Pusa Baisakhi and PS7 (Panwar et al., 1988). The determinate and indeterminate habits of pulse crops also affect the leaf area development and biomass production. In pulses maximum leaf area is generally achieved at the flowering stage, and then it declines towards maturity. During pod development stage translocation of assimilates, leaf and stem nitrogen and other nutrients takes place towards developing grains, which induces senescence of leaves (Sinclair and deWit, 1976). The senescence of leaves is also attributed to be mediated through the hormonal signal (Nooden et al., 1979) or a combination of nutrient and hormonal signals. The senescence of leaves can be delayed by using cytokinins (kinetin/benzyl adenine), CO<sub>2</sub> enrichments or through grafting. Use of benzyl adenine (20 ppm) enhances chlorophyll content, photosynthetic rate and maintains leaf area duration, whereas etrel enhances the senescence of leaves. Benzyl adenine has enhancing effect on nodulation and nitrogen fixation in pulses. However, by girdling Panwar et al. (1988) and Abbas et al. (1996) observed drastic reduction in nodulation and nitrogen fixation effects in mungbean. In a CO<sub>2</sub> enriched environment soybean plants showed higher nodulation, nitrogen fixation and vesicular arbuscular mycorrhiza (VAM) activation as compared to those plants that were grown under ambient CO<sub>2</sub> condition (Rygielwicz et al., 1994).

In clover, defoliation and shading resulted in significant reduction in total nodule number and nodule dry weight per plant, and average dry weight per nodule. Defoliation also led to degradation of leghaemoglobin, even in less than three days after treatment, resulting in marked reduction in nitrogen fixation capacity of the nodules (Chu and Robertson, 1974). Osman et al. (1983) also observed similar effects of defoliation on nodules and nitrogen fixation in peanut.

In mungbean source-sink relationship studies has indicated that defoliation of plants reduced the nodule dry weight and nitrogen fixation



ability, where as removal of flowers and pods (sink) resulted in enhanced values for both the parameters (Bathlenfalvey et al., 1978) (Table 2).

**Table 2.** Nodule dry weight and their nitrogen fixation ability as influenced by defoliation and removal of flowers and pods in mungbean.

Treatment	Nodule dry weight (mg/plant)	Nitrogen fixation (mg/plant)
Control plant	298	475
Defoliated plant	176	266
Plants with flower/pods removed	430	548

Source: Bathlenfalvey et al., 1978

The reduced nodulation and nitrogen fixation in defoliated plants is attributed to non-availability of current photosynthates for nodulation, nodule growth, and for nitrogen fixation (Sirclair and deWit, 1976). Gordon et al. (1986) reported initial decline in nitrogen fixation and respiration after defoliation in white clover. Nitrogen fixation again increased to the control levels as new leaves appeared. The initial decline in nitrogen fixation and respiration rate was found not to be associated with the instantaneous carbohydrate content of the nodules, but rather to the supply of current photosynthates from the shoot to nodules. It is also reported that application of urea (0.5%) as spray at pod initiation stage delays senescence in mungbean and increases grain yield. Similar results were also obtained in chickpea (Panwar and Singh, 2008).

As compared to other pulse crops, juvenile growth is also very poor in pigeonpea (Aftab Hussain et al., 1993). At seedling stage the net assimilation rate (NAR) in pigeonpea is relatively low due to smaller leaf area (Sheldrake and Narayanan, 1979). Narayanan et al. (1981) reported that seedling growth rate is faster in large-seeded genotypes of pigeonpea. Leaf area index (LAI) of crop is reported to increase exponentially unless canopy started to close and by that time older leaves are observed to start abscising. Thereafter, the rate of leaf area expansion is slowed down. Leaf area index ultimately attains its maximum value when rate of new leaf development is balanced by the abscission of older leaves. Leaf area index is retained at the maximum level for variable times depending upon genotype and the environmental condition (Lawn and Iroedson, 1990). Biomass accumulation in pigeonpea is essentially a linear function of amount of photosynthetically active radiation intercepted by the crop canopy, which is a function of leaf area index (Hughes et al., 1981; Hughes and Keatinge, 1983).

It has been observed that the canopy development and dry matter production in chickpea is very low as compared to other crops, except

pigeonpea. Full canopy development may be attained during flowering and active pod development stages. Leaf area index in chickpea ranges from 2 to 4. In chickpea, vegetative growth, and flowering and pod development continues, therefore, reproductive phase rarely coincides with maximum LAI attainable. As a result of this, the grain development stage does not get opportunity to take advantage of full light interception.

### Light Interception

Light interception and biomass accumulation are the linear function of the amount of PAR (photosynthetically active radiation) intercepted by the crop canopy, and is a function of LAI. The proportion of incident energy intercepted by crop canopy,  $I/I_0$ , is calculated as a function of the leaf area index, and expressed as follows:

$$I/I_0 = 1 - \exp(-k \times \text{LAI})$$

where  $k$  is the extinction coefficient of the canopy, and is characteristic of a crop canopy. For a given crop species variable values for  $k$  have been reported (Varlet-Grancher *et al.*, 1989). Variations occur due to differences in measurements and to the environmental conditions. Crop influence on  $k$  is through orientation, angle, size and partial dispersion of leaves. These parameters are affected by genotype and water status of the plant. For smaller and lanceolate leaves,  $k$  may be as low as 0.3 in pigeonpea (Rowden *et al.*, 1981). In pea it is difficult to calculate  $k$  as some of the leaves are transformed into tendrils. The critical LAI also depends upon  $k$  value, and for pigeonpea critical LAI varies from 3.9 (Muchow, 1985) to more than 6.0 (Rowden *et al.*, 1981). During the reproductive growth phase, floral structure and developing pods intercept an increasing proportion of PAR and it is more significant in determinate genotypes than in indeterminate types with apical inflorescence. The slope of linear relationship between biomass production and cumulative PAR interception is the indication of plant's efficiency to convert radiation energy into chemical energy. The  $k$  values vary with the canopy position (upper canopy 0.35 and lower canopy 0.84) as per Thirathon *et al.* (1987), and may be near optimal.

In chickpea, it is reported that the LAI and light interception varies from one genotype to another, and it also depends on prevailing agro-climatic condition. The LAI under rainfed condition is lower than that under irrigated condition. For example the LAI remains less than 1, even after 80 days of sowing when flowering commenced in early type (JG 62) (Aggarwal *et al.*, 1984). The LAI reaches about three when pod formation starts at about 100 days after sowing.

With the occurrence of growth the older leaves start senescing. The process is accelerated under nitrogen deficiency and water stress. As indicated earlier in this chapter, leaf area of crop increases up to flowering and then declines during grain development. Maintenance of leaf area



duration is an important parameter of crop plants that helps in assured availability of current photosynthates to grains during their development (Sinha *et al.*, 1988; Ghildiyal *et al.*, 1998).

### Root Architecture of Pulse Crops

The term architecture usually denotes the spatial configuration of some complex assemblage of subunits, with the implication that the overall configure has some functional significance. The term root architecture has been used in various contexts to refer to distinct aspects of shape of root system. It usually does not include root hairs, but is concerned with the entire root system or a large subset of the root system of an individual plant. Root architectures are generally quite complex.

The entire growth and development of plant depends upon the growth of roots. Root emerges out first during germination and is called an axis, when it develops from the seed (seminal axis) or the stem (nodal axis). Tap root system is predominantly found in all the pulse crops, and its further development affects growth and development pattern of the plant. Roots arising from the axis are designated first order laterals, and those branching from first order lateral are designated as second order laterals and so on (Wu *et al.*, 2005). Laterals emerge from each number of the next lower order in acropetal sequence. The oldest lateral is normally located from the base point by a basal non branch distance. In plants root characteristics are directly related to nutrient and water uptake, enhanced lodging resistance, drought tolerance, and tolerance to mineral toxicity. Roots are also the primary source of growth regulators like gibberellins and cytokinins. Phytoremediation by roots help in reclamation of soil.

Lynch (1995) studied the root architecture of common bean seedling at 14 days of age. The common bean is typical of many herbaceous dicots in having a tap root and a crown of basal roots from which lateral roots emerge. Root system exhibits considerable architectural variations among species, among genotypes of given species, and even in different parts of a single root system. The diversity and plasticity of root architecture are simultaneously a daunting methodological challenges and an intriguing aspect of the functional morphology of the plants. Roots can be divided as spreading, semi-spreading and deep penetrating types. Depth of rooting is often cited as an important criterion as it has a major influence in determining the potential supply of water from the deeper soil layers. Deeper rooting leads to improved yield stability under limited water environment (Chaudhary *et al.*, 1992 and Panwar *et al.*, 2008). Drought has been the main factor in loss in yield. About 3.7 million tonnes of chickpea and 1.8 million tonnes of pigeonpea have been reported to be lost per annum globally due to drought (Subbarao, *et al.*, 1995 and Serraj *et al.*, 2004). In Australia alone 30% reduction in yield due to drought has been reported (Horridge *et al.*, 2005). Pulses are grown under water limited environment and the genotype with improved tolerance to limited



water supply, combined with management practices, are needed to maximize water availability to them and maximizing yield under limited soil moisture condition (Passioura, 2006). Root related adaptive traits of pulses are quite important in understanding the crop and varietal performance under various agro climatic conditions, but limited literature are available pertaining to root system. It is considered that root architecture may be one of the most important criteria to judge the crop and varietal performance under different soil moisture conditions.

The root architecture very much depends upon the crop, genotype, soil nutrient status, soil-plant-water relationship and soil structure. However, it is reported that the tolerant line of common bean extracts more soil water and therefore, canopy temperature differential between stressed and irrigated plots were less for the two drought tolerant genotypes; A 70 and BAT-1224. Deeper root system enables plants to maintain transpiration rates under drought by the extraction of soil moisture from the deeper zone in the soil profile. Greater root growth was found to be associated with drought tolerance in bean grown in fertile soil, suggesting that drought avoidance by the increased extension of soil moisture, from deeper soil layers is an important drought resistance mechanism in common bean.

The orientation of newly emerged laterals is controlled by two variables, i.e. insertion angle and radial angle. The insertion angle is the angle between the mother root and the branch in the plane containing two roots, while the radial angle is the angle between the branch dissected and a specific reference direction in the plane perpendicular to the mother root. In 32 day-old soybean plants, which is having tap root system, it has been observed that lateral roots accounted for 99% of the total root length and 98% of the total root surface area (Kono et al., 1987). For other legume species such as chickpea, cowpea, grass pea (*Lathyrus*), lentil, urd bean and mungbean also lateral roots are reported to be major component of their root system (Mia, 1996).

Root architecture traits determine *in situ* space filling properties of a root system or root architecture. The growth angle of root axis is a principal component that has been strongly associated with the acquisition efficiency of many plant species. The growth angle and number of seminal roots showed significant variation even in wheat genotypes ranging from 36 to 56 degree and 3 to 5 per plant (Manschedi *et al.*, 2006). Heavy plasticity and further growth of roots, even when the rain occurs after the gap of a long period, has been attributed as one of the reasons associated with better adaptability of cowpea genotypes with indeterminate growth under intermittent drought (Sinha *et al.*, 1988).

### Root Depth and Root Length Density

In plants water status is controlled by roots, similarly roots are the main organ for meeting out the transpirational demand of plants. Two major dimensions describe the ability of plant to extract soil moisture; and



these are: (i) root depth, and (ii) root length density. The more important dimension is the root depth. It is a primary component of drought resistance. The development of lateral roots at very shallow soil depth has a role in capturing small amount of intermittent rainfall. Various experiments conducted at IIPR Kanpur under rainout shelter bed and the drought plots revealed the genotypic variations with respect to rooting depth. Genotypic variations have been observed in root architecture in chickpea (Anonymous, 2005). Several experiments conducted using special root structures at the AICRP, Bangaluru for the last 6-7 years have revealed significant variations in root growth among the pigeonpea genotypes and genotypes having this trait have ultimately been selected as donor parents to breed for drought tolerant pigeonpea genotype (Anonymous, 2004-2011)

Root size, morphology, root length density, hydraulic conductance and functional activity of root are basic features to meet out the transpirational demand of shoot (Passioura, 1982). For maximizing extraction of soil moisture, the requirements are; deep penetration of root, adequate root density in deeper root zones, and adequate longitudinal hydraulic conductance of roots (Fischer et al., 1982). The water uptake across the depth of rooting zone is not uniform. In general, nearly 40% of the total rooting water uptake occurs from the first one forth of the rooting zone, 30% from the second, 20% from the third, and the remaining 10% from the last one-fourth region of the total rooting depth (Doorenbos and Pruitt, 1975; Nageshwerarao and Wright, 1994). Crop plants often maintain higher root length densities than required in the surface layer to facilitate rapid uptake of recent rain before it evaporates, to provide reserve capacity in case of disease and pest damage, to extract relatively immobile nutrients and to compete with weeds and other plants for both water and nutrient (Passioura, 1983). Depending upon the target environments, certain root traits may be more important than others and targeting the genetic improvements depends upon the types of traits required relative to those present in current cultivars. Many drought environments present a situation where rainfall is low and soil depth that contains moisture is permanently shallow. Under such situation depth of rooting and plants ability to sustain an uninterrupted supply of water are important factors for survival (Gregory, 1988).

A wide genotypic variability among root characteristics such as density, depth and total root biomass has been reported in chickpea. Saxena et al. (1989) and Krishnamoorthy et al. (1996) identified chickpea genotypes with drought tolerance through increased root biomass. A drought resistant genotype ICC 4958 has 30% higher root dry matter than the drought sensitive genotype; Annigeri. Genotypic variations in rooting length, density, morphology, dry matter, branching pattern and dynamics were studied at IIPR, Kanpur using 16 chickpea genotypes, and concluded that well developed root system may contribute towards higher yield (Basu



and Singh, 2003). Genotypes ICC 4958, K 850, ICCV 92944, already known as drought tolerant, are having profuse rooting system. Working on rooting behaviour under water stress, Kashiwagi et al. (2006) has demonstrated that recombinant inbred lines (RILS) with ICC 4958 and Annigeri have wider variations in relation to root length density. Another QTL mapping approach for root associated drought avoidance traits in chickpea are being tried at the ICRISAT.

Early-maturing genotypes of chickpea ICC 4958 has multiple traits such as larger root size, a rapid rate of root development and extraction of water, and a rapid rate of seed development resulting in larger seed size. Lines ICC 5680 and ICC 10480 have a smaller leaf area, due to either narrower pinnules or fewer pinnules (CC 5680). Recombinants with traits of ICC 4958 and ICC 5680 have shown a higher mid day leaf relative water content compared to the parents in field trials (Saxena, 2003).

In pigeonpea, yield advantage has been reported by using traits such as extra short duration genotypes, viz. ICPL 87 and ICPL 83015 (Nam et al., 1993), leaf area maintenance in ICPL 87 (Lopez et al., 1996), root and shoot biomass accumulation in ICPH 8, ICPH 9 (Chauhan et al., 1998) and by low drought susceptible index in ICPL 86039 (Chauhan et al., 1998).

Root traits is one of the most important components of drought tolerance in plants. Root system is a primary sensor of drought stress (Davies and Zhang, 1991). To work on roots is a laborious and time consuming process, and at the same time the root hairs and minor roots are neglected in such studies. Use of mini-rhizotron placed at different depths parallel to the soil surface to screen the genotypic differences in relation to tolerance to drought by measuring even small roots and root hairs has been demonstrated by Panwar (2006) and Panwar (2008). However, there is a limited knowledge of root system and there is a need of simple and efficient technique to study root associated traits.

## REFERENCES

- Abbas S.; Panwar, J. D. S. and Sita Ram. 1996. Experimental evidence of plant senescence by growth regulators in Y-shaped mungbean plants. *Indian J. Plant Nutrition*. **6**: 11-14.
- Aggarwal, P. K.; Khanna Chopra, R. and Sinha, S. K. 1984. Changes in leaf water potential in relation to growth and dry matter production. *Indian J. Exp. Biol.* **22**: 98-101.
- Anonymous. 2004-2011. *Annual Reports*, & AICRP (Pigeonpea), IIPR, Kanpur, 2004-2011.
- Anonymous. 2005. Traits for yield improvement of chickpea in drought-prone environment of India and Australia. *ACIAR-ICAR Project Report CIM/1996/07-1999*. <http://aciar.gov.au/project/CIM/1996/007>



- Baldev, B.; Ramanujam S. and Jain, H. K. (1998) *Pulse Crops: Grain Legume*. Oxford and IBH Publishing, New Delhi, India.
- Basu, P. S. and Singh, D. N. 2003. Physiology and abiotic stress in chickpea. *In: Chickpea research in India*. Ali M., Kumar, Shiv and Singh N. B. (Eds). IIPR, Kanpur. pp. 137-66.
- Bathlenfalvey, G. J.; Pacovosky, R. S. and Brown, M. S. 1978. Parasitic and mutualistics association between a mycorrhizal fungus and soybean: Development of endophyte. *Phytopath.* **72**: 894-97.
- Chaudhary, B. D.; Pannu, R. K.; Singh, V. P.; Singh, D. P. and Singh, P. 1992. *Ann. Bot.* **8**: 13-27.
- Chauhan. Y. S.; Wallace, D. H.; Johansen, C. and Singh, L. 1998. Genotype  $\times$  environment interaction effect on yield and physiological basis in short duration pigeonpea. *Field Crop Res.* **59**: 141-50.
- Chu, A. C. P. and Robertson, A. G. 1974. Effect of shading and defoliation on nodulation and nitrogen fixation by clover. *Plant & Soil.* **41**: 509-19.
- Davies, W. J. and Zhang, J. 1991. Root signals and the regulation of growth and development of plants in drying soil. *Ann. Rev. Plant Physiol. Mol. Biol.* **42**: 55-76.
- Doorenbas, J and Pruitt, W. O. 1975. Guidelines for predicting crop water requirement. FAO irrigation and drainage, Paper No. 24. FAO, Rome, Italy.
- Fischer, K. S.; Johenson, E. C. and Edmeades, G. O. 1982. Breeding and selection of drought resistance in tropical maize. *In: Drought Resistance in Crop Plants with Emphasis on Rice*. IRRI, Phillipines, pp. 377-99.
- Ghildiyal, M. C.; Sharma-Natu, Poonam and Khan, F. A. 1998. Photosynthetic acclimation to elevated CO<sub>2</sub> in relation to saccharides content in wheat and mungbean leaves. *Indian J. Exp. Biol.* **36**: 217.
- Gordon, A. J.; Ryle, G. J. A.; Mitchell, D. F.; Lowry, K. H. and Powell, C. E. 1986. Effect of defoliation on carbohydrate, protein and leghaemoglobin content of white clover nodules. *Ann. Bot.* **58**: 141-54.
- Gregory, P. J. 1988. Root growth of chickpea, fababean, lentil and pea and effect of water on salt stress. *In: World Crops: Cool Season Food Legumes*. Summerfield R. J. (Ed). Kluwar Academic Publisher, London, UK, pp. 857-67.
- Horridge, M.; Madden, J. and Witter, G. 2005. The impact of 2002-03 drought on Australia. *J. Policy Modelling.* **27**: 285-308.
- Hughes, G and Keatinge, J. D. H. 1983. Solar radiation interception, dry matter production and yield of pigeonpea (*Cajanus cajan* (L.) Millsp) *Field Crop Res.* **6**: 171-78.
- Hughes, G., Keating, J. D. H. and Scott, S. P. 1981. Pigeonpea as a dry season crop in Trinidad, West Indies. II Interception and utilization of solar radiation. *Tropical Agric. (Trinidad).* **58**: 191-99.
- Kashiwagi, J.; Krishnamurthy, L.; Singh, S.; Gaur, P. M.; Upadhyay, H. D.; Panwar, J. D. S.; Basu, P. S.; Ito, O. and Tobita, S. 2006. Relationship between

transpiration efficiency and carbon isotope discrimination in chickpea. (*C. arietinum* L.). *International Chickpea & Pigeonpea News Letter*. **13**: 19-21.

Kono, Y.; Yamauchi, A.; Nonoyama, T.; Tatsumi, T. and Kawamura, N. 1987. A revised system of root-soil interaction for laboratory work. *Environ. Control Biol.* **25**: 141-51.

Krishnamorthy, L.; Johansen, C. and Ito, O. 1996. Genotypic variations in root system development and its implications for drought resistance in chickpea. *In: Roots and Nitrogen in Cropping Systems of the Semi Arid Tropics*. (Adu-Gyamfi J. J., Katayama K., Kumarrao J. V. D. K. and Rego T. J., (Eds). *International Res. Centre For Agric. Sci. (JIRCAS), Ibarask, Japan.* **3**: 235-50.

Lawn, R. G. and Iroedson, R. J. 1990. Pigeonpea: Physiology and yield formation. *In: The pigeonpea*. (Nene Y. L., Holland S. D. and Shiela V. K., (Eds). CAB International, Wallingford, UK, pp. 179-208.

Lopez, F. B.; Chauhan, Y. S. and Johansen, C. 1996. Effect of timing of drought stress on abscission and dry matter partitioning of short duration pigeonpea. *J. Agron. Crop Sci.* **177**: 327-38.

Lynch, J. 1995. Root architecture and plant productivity. *Plant Physiol.* **109**: 7-13.

Mauschedi, A. M.; Christopher, J.; deViol, P. and Hamm, G. L. 2006. The role of architectural in adaption of wheat to water limited environment. *Functional Plant Biol.* **33**: 823-37.

Mia, M. W.; Yamanchi, A. and Kono, Y. 1996. Root system structure of six food legume species inter and intra-specific variations. *Japan J. Crop Sci.* **65**: 131-41

Muchow, R. C. 1985. Phenology, seed yield and water use of grain legumes grown under different soil water regimes in a semi arid tropical environment. *Field Crop Res.* **11**: 81-97.

Nageshwararao, R. C. and Writ, G. C. 1994. Stability of the relationship between specific leaf area and carbon isotopic discrimination across environments in peanut. *Crop Sci.* **34**: 98-103.


Nam, N. H.; Chauhan, Y. S. and Johansen, C. 1993. Comparison of extra short duration pigeonpea with short season legumes under rainfed conditions on alfisol. *Exp. Agric.* **29**: 307-16.

Narayanan, A.; Saxena, N. P. and Sheldrake, A. R. 1981. Varietal differences in seed size and seedling growth in pigeonpea and chickpea. *Indian J. Agric. Sci.* **51**: 389-93.

Nooden, L. D.; Kahanak, G. M and Okaten, Y. 1979. Prevention of monocarpic senescence in soybean with auxins and cytokinin an antidote for self destruction. *Science.* **206**: 851-53.



- Osman, A. K.; Wynne, J. C.; Elkan, G. H. and Schneeweis, T. J. 1983. Effect of leaf removal on symbiotic nitrogen fixation in peanut. *Peanut Sci.* **10**: 107-10.
- Panwar, J. D. S.; Sudhir Kumar and Vandana Chaudhari. 2008. Drought tolerance in chickpea: Physiological, biochemical and biotechnological approaches. *In: Development in Physiology, Biochemistry and Molecular Biology of Plants*. Vol. 2. Bandana Bose and A. Hemantaranjan, (Eds). New India Publishing Agency, New Delhi, India, pp. 307-40.
- Panwar, J. D. S. and Singh, Attar. 2008. Effect of foliar application of urea (2 %) on growth, yield and grain quality in four chick pea cultivars under rainfed condition. Annual Report, Division of Plant Physiology, IARI, New Delhi.
- Panwar, J. D. S. 2006. Advancing fine root researches *in situ* using mini rhizotron on chickpea genotypes grown under rainfed condition. *ICAR NewsLetter*. **12**: 3
- Panwar, J. D. S. 2008. Rooting behaviour in relation to drought in pulses. Non-destructive method for root studies *In: Rhizosphere: Strategies for Augmenting Soil Fertility and Productivity*. Shivdhar, Manjaiah K. M., Annapurna K. and Rai R. K., (Eds). pp. 524-31.
- Panwar, J. D. S.; Chandra, R. and Sirohi, G. S. 1988. Effect of temperature on growth, nodulation and nitrogen fixation in summer mung (*Vigna radiata* (L.) Wilczek.). *Ann. Plant Physiol.* **2**: 121-29.
- Passioura, J. B. 1982. The role of root system characteristics in the drought resistance of crop plants. *In: Drought Resistance in Crop Plants with Emphasis on Rice*. IRRI, Phillipines. pp. 71-82.
- Passioura, J. B. 1983. Root and drought resistance. *Agric Water Manag.* **7**: 265-80.
- Passioura, J. B. 2006. Increasing crop productivity when water is scarce from breeding to field management. *Agric. Water Manag.* **80**: 176-96.
- Rowden, R.; Gardner, D.; Whiteman, P. C. and Wallis, E. S. 1981. Effect of planting density on growth, light interception, and yield of a photoperiod insensitive pigeonpea (*Cajanus cajan*). *Field Crop Res.* **4**: 201-13.
- Rygiewicz, P. T.; Johnson, M. G.; Storm, M. J. and Tingey, D. T. 1994. Life history and carbon partitioning of ectomycorrhizal fungi on the roots under elevated carbon-di-oxide concentration. Abst ; First GCTE Science Congress held at Woodhole, Massochester, USA 23-27 , May 1994. p. 105.
- Saxena, K. B.; Laxman.Singh; Gupta, S. C.; Chauhan, Y. S. and Reddy, M. V. 1989. Hybrid pigeonpea, development and prospects. *Proceeding of Strategies for Increasing Pulse Production*. 3-4 January, 1989 at ARS Badnapur, Maharastra.

- Saxena, N. P. 2003. Management of drought in chickpea-a holistic approach. *In: Management of Agricultural Drought-Agronomic and Genetic Options*. Saxena N. P., (Ed). Oxford IBH Publishers Co. Pvt. Ltd, New Delhi, India, 103-122.
- Serraj, R.; Buhariwalha, H. K.; Sharma, K. K.; Gaur, M. P. and Crouch, J. H. 2004. Crop improvement of drought resistance in pulses: A holistic approach. *Indian J. Pulses Res.* **17**: 1-13.
- Sheldrake, A. R. and Narayanan, A. 1979. Growth, development and nutrient uptake in pigeonpeas. *J. Agric. Sci.* **92**: 513-26.
- Sinclair, T. R. and deWit, C. T. 1976. Photosynthesis and nitrogen requirement for seed production of various crops. *Science*. **189**: 565-67.
- Sinha, S. K.; Bhargava, S. C. and Baldev, B. 1988. Physiological aspects of pulse crops *In: Pulse Crops: Grain Legume*. Baldev B., Ramanujam S. and Jain H. K., (Eds). Oxford and IBH Publishing, New Delhi, India.
- Subbarao, G. B. V; Johansen, C.; Shrikard, A. E.; Rao, R. C. N.; Saxena, N. P. and Chauhan, Y. S. 1995. Strategies for improving drought resistance in grain legumes. *Critical Rev. Plant Sci.* **14**: 469-523.
- Thirathon, A.; Byth, D. E.; Fischer, K. S. and Whiteman, P. C. 1987. Relationship between leaf area, radiation interception and dry matter production after flowering in short season pigeonpea. Food legume development for Asian farming system. Proceedings of the International Workshop in Pigeonpea. Khon Kaen, ACIAR, Canberra, pp. 252-53.
- Varlet-Grancher, C. and Bonhomme, R. 1974. Utilisation de l'énergie solaire par une culture de *Vigna sinensis*. III : Evolution du rendement énergétique pendant la phase végétative. *Ann Agron.* **25**: 811-19.
- Wu, L.; McGechan, M. B. and Mc Robert, N. 2005. Developing existing plant root system. *Adv. Agron.* **85**: 181-219.
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## CHAPTER 4

# Biology of Symbiotic Dinitrogen (N<sub>2</sub>) Fixation in Pulses

Nitrogen is a major component of our planet occurring either in free N<sub>2</sub> or in various inorganic and organic forms. However, 98% of global N occurs in primary rocks, and is unavailable to organisms. The largest part of the remainder is found in atmosphere as N<sub>2</sub>. It has been estimated that the reservoir of atmospheric N is  $3.9 \times 10^{15}$  tonnes. Terrestrial living systems contain only  $1 \times 10^{10}$  tonnes, or about  $25 \times 10^{-6}$  % N of that present in the atmosphere. The ability to reduce atmospheric dinitrogen, i.e. conversion of N<sub>2</sub> to ammonia, is limited to prokaryotes. Legumes and a few other plant species have the ability to fix atmospheric N<sub>2</sub> through symbiotic relationships with prokaryotes. In legumes the N<sub>2</sub> fixation is carried out generally by *Rhizobium* or *Bradyrhizobium*, present in nodules located on the plant roots (Sprent and Sprent, 1990).

In warm climates, bacteria of the genus *Beijerinckia* are active as free-living nitrogen fixing organism. Representatives of the bacterial genus *Azotobacter* were regarded, for many years, as the principal free living agents of nitrogen fixation in soils of temperate zone. In soil anaerobic nitrogen fixing bacteria, principally *Clostridium*, is usually several thousand times greater in number than *Azotobacter*. Other microbes that have been reported to be capable of nitrogen fixation include a variety of soil, mud and water bacteria (including *Pseudomonas*, *Spirillum*, *Azotobacter*, *Desulfovibrio*) and two types of yeasts. Mycorrhizal infection of green gram positively influences rhizobial colonization for better nodulation and N fixation in this crop (Balachandar *et al.*, 1999; Panwar and Thakur, 1995; Rathi *et al.*, 2000).

Biological N<sub>2</sub> fixation is estimated to convert  $175 \times 10^6$  tonnes of N from dinitrogen to ammonia every year, whereas at global level; industrial processes fix about  $60 \times 10^6$  tonnes of nitrogen annually. Soybean plants, by forming a symbiotic association with the bacteria; *B. japonicum*, can fix up to 200 kg atmospheric N/ha/year (Smith and Hume, 1987). Nitrogen fixation is a highly energy intensive process and consumes 6.5g carbon/g of N fixed (Kennedy, 1997).

Family Rhizobiaceae consists of a heterogeneous group of gram negative, aerobic, non-spore forming rods that can invade and form nodules on the root, and in some instances on the stem of leguminous plants (McCardell *et al.*, 1993). Slow growing nodulation bacteria, which have specific association with soybean, are referred to as *Bradyrhizobium*. Currently, *Bradyrhizobium* has only one designated species, *B. japonicum*. Some soybean roots can also form nodules with a fast growing bacteria named as *Rhizobium fredii* (Sprent and Sprent, 1990). It is estimated that different pulse crops fix 17-285 kg N/ha. In India, pulses are annually grown on an area of about 23 million hectares with a total production of 13 million tonnes. Assuming the average quantity of N fixed by different pulse crop as 100 kg N/ha, the pulses contribute approximately 2.4 million tonnes of nitrogen per annum.

Nitrogen fixation by different pulse crops, as given by various workers, and the estimated values for each crop are given in Table 1.

**Table 1.** Nitrogen fixation by different pulse crops and the estimated values for some pulse crops

Crop	Nutman (1976 ) (kg N/ha)	Subbarao (1988) (kg N/ha)	Estimated (kg N/ha)
Chickpea	41-270	26-63	41-270
Lentil	55-77	35-100	62-103
Field pea	46-115	46	30-140
<i>Vicia faba</i>	-	-	121-171
Mungbean	55-110	50-55	31-85
Cowpea	73-124	53-85	73-240
Soybean	17-124	-	17-124
Pigeonpea	41-90	68-200	31-285

Inoculation of chickpea with *Rhizobium* is a profitable and cheapest agronomic practice for augmenting production. Chickpea sown in rice fallow responds to *Rhizobium* inoculation, however, *Rhizobium* under residual soil moisture, fails to enter in the root in the absence of sufficient moisture. Thus, in moisture limiting soils nodulation remain poor; even after *Rhizobium* inoculation. Application of fertilizer nitrogen @ 30 kg N/ha increases yield of chickpea by 25.7% over the control (Gupta and Namdeo, 1996). Nodule number and nodule weight exhibit a positive correlation with grain yield in chickpea.

Rangarajan and Prabhakaran (1980) reported biological nitrogen fixation and symbiotic efficiency between pigeonpea and *Rhizobium* strains. Coir-dust application with peat seed inoculation showed



significantly higher seedling vigour index, plant biomass, nodule number and nodule biomass (Prabhakaran and Srinivasan, 1995). Significantly higher yield (1080 kg/ha), i.e. 50 per cent higher than the control, was obtained in coir dust + seed inoculation with *Rhizobium*. There has been 15 per cent yield increase in coir dust + seed inoculation treatment than seed inoculation alone with *Rhizobium* (Prabhakaran and Srinivasan, 1995). Similar effect of organic amendments and seed inoculation has been reported by Palaniappan *et al.* (1983).

### Nodule Formation

Nodulation begins when *Rhizobia* attach themselves to epidermal cells of root. Epidermal cell with immature root hairs are the usual sites for bacterial penetration. Prior to attachment, communication between the two symbiotic partners is required and a certain minimum period of contact is needed. Infected root hairs are always shorter than mature intact root hairs, due to marked curling upon infection. The host cell wall is degraded and a pocket is formed by the curled root hair, and the bacteria invade the cell through the degraded portion of the wall (Challaham and Torrey, 1981). At the point of infection, the root hair wall forms a depression that invaginate deeply, forming an infection thread lined by a continuation of the root hair wall and membrane. Infection thread may branch within a root hair. The infection thread, with its invaded dividing bacteria grows 60-70  $\mu\text{m}$  to the base to the root hair cell. The cortex adjacent to infected root hairs becomes meristematic and produces a wedge-shaped area of dividing cells even before any infection thread enters in it. Then due to mitosis there is an increase in cell number in this region of the cortical layer, and it becomes the main area of *Rhizobia* infected cells. The combination of multiple threads and branching of threads in the cortex results in penetration of many *Rhizobial* infected threads. The peripheral uninfected area becomes the nodule cortex which includes a scleroid layer and several vascular bundles. Sometimes during or following mitotic activity, *Rhizobia* are released into cortical cells through thin areas on the tips of the infection threads. The *Bradyrhizobia* are called bacteroids after their release into the host cells. Their cell walls are considerably modified, but in case of groundnut cell walls are entirely removed.

Bacterial attachment to root hairs occurs within minutes of inoculation and is followed within 12 hours by marked curling of root hairs. Infection threads, first visible within 24 hours of infection, reach the base of the root hair after 48 hours of inoculation. By this time period, anticlinal division of the adjacent cortical cells occurs, giving rise to nodule primordial. Infection thread penetration of this extensively dividing meristem is not observed until 48-96 hours after inoculation. Bacteria are released from the infection thread to form bacterioids within 7-10 days after inoculation. A spherical mass of cells rich in cytoplasm, which have been invaded by infection threads, divide and differentiate into the central zone of N<sub>2</sub>-fixing cells by 12-18 days after inoculation.



Mitosis in infected cortical cells ceases about 14 days after infection. Subsequent increases in the volume of infection tissue are due entirely to cell enlargement. As the nodule matures, oxygen binding pigment, leghaemoglobin, develops gradually in the host tissue and the nodule becomes pink in colour. With the formation of leghaemoglobin the contained bacteria cease to divide and dinitrogen fixation commences in the nodule.

Nodule initiation and development depends on the expression of host and microsymbiont genes. Variations in either host or bacterial genomes may affect the sequence of nodule development and the expression of the genes involved in nitrogenase activity and regulation. In some cases root hairs and nodules occur only where lateral roots emerge (Dongre *et al.*, 1985).

According to O'Neill (2007), before the discovery of Haber-Bosch process for synthesizing ammonium nitrate in 1912, lightening bolts in thunder storms and nitrogen fixation by soil microbes were the only natural source of nitrate for plant growth. Most plants absorb soluble nitrate or ammonium from the soil, but only one group of plants, i. e., legumes form an extraordinary biological association with N fixing *Rhizobia* that fix atmospheric nitrogen and supplies to legume plants in symbiotic manner.

An understanding of signaling mechanisms that establishes the symbiosis between plant and microbes could allow plant scientist so make non-legume plants such as cereals capable to fix atmospheric nitrogen.

### Legume-Mycorrhizal- *Rhizobium* Symbiosis

In both *Rhizobia* and mycorrhizal symbiosis, it is the plant that initiates the conversation by sending signal by secreting phenolic compounds from its roots into the rhizosphere. The secreted flavanoid, PHGalactose, appears to be unique signal that initiates the conversation between the legume plant and free living microbes (John Innes, 2007). Different plant taxa secrete 'customized' array of phenolic signals that mediates their interaction with the specific symbionts. While working on *Lotus japonicus* and *Medicago truncatula* Oldroyd (one of the leading world's researcher in legume symbiosis) and his associates reported that the legumes biochemical 'wink' elects a *nod* factor in response that activates genes in the bacterium, resulting in secretion of extremely potent signaling molecular, the *nod* (nodulation) factor. The *nod* factor in turn triggers cortical cell in the plant's roots to expand and proliferate, forming a distinct root nodule that accommodates the N fixing bacteria. It has been demonstrated that extremely low concentration of pure nod factor are sufficient to induce nodule formation (O'Neil, 2007). Initiation of symbiosis starts with attachment to root-hair cells of plant. Root-hair cell curl around the bacteria entrapped, and results in successful infection of plant with *Rhizobium*.



## Leghaemoglobin

The *Rhizobium* infection is initiated by a single cell, which then spawns a clonal population of specialized cells called bacteroids that remains in the protected environment of the root nodules through out the life of the plant (Oldroyd, 2007). When the plant dies, millions of bacteria are released from the decaying nodules into the rhizosphere, which further repeat the cycle.

Within the nodules, the bacteroids produce an enzyme, **nitrogenase**, to reduce atmospheric nitrogen to ammonia. Ammonia is then exported to the host plants. The leghaemoglobin, present in nodules, is an iron rich plant protein that fulfills the same basic function in the plant's tissues as haemoglobin in animal blood. Leghaemoglobin acts as oxygen scavenger and supplies oxygen to the nodule's microbial tenants at a very low and constant tension. Excess oxygen tension in nodules suppresses the high energy, anaerobic activity of nitrogenase. A diffusion barrier around the nodule also regulates the entry of oxygen and other gases, but permits the import of the photosynthetic product dicarboxylic acids, which fuels the high energy nitrogen fixing process.

## Fungal Symbiosis

Oldroyd's laboratory has evidently shown that the *nod* factor of microbes initiates nodule growth by activating several receptors like protein kinases in the cells of host. By introducing a mutation into one of the genes, they identified a calcium-dependent receptor like kinase. They created medicago plants that developed root nodules spontaneously even in the absence of the bacterial *nod* signal. The *nod* factor de-represses the inactive plant gene and induces complex downstream gene activity that developes complete root nodules with the supply of leghaemoglobin. Activation of the gene further induces pronounced oscillations in calcium levels in the cell nucleus. When calcium spiking was suppressed with calcium chelators, the plants did not develop root nodules, which indicated that calcium serves as a secondary messenger within the cell nucleus. Oldroyd concluded that calcium spikes probably coordinates downstream genes involved in nodule formation, or may organize the root hair curling that allows *Rhizobium* to infect the plant successfully.

The leghaemoglobin gene, once through exclusive to legumes, is now known to be present in higher plants, and legumes are not the only plants to exploit its oxygen carrying capabilities to support nitrogen fixing symbionts. Around two decades ago, researchers discovered that a New Guinea rainforest tree, *Parasponia andersonii*, a distant cousin of elms (Ulmaceae) independently evolves a nitrogen fixing symbiosis with *Rhizobia* bacteria specifically, with *Bradyrhizobium*. Members of the Australasian genera, *Casuarina* and *Allocasuarina*, also form nitrogen fixing symbiosis and develop root nodules, but with a mycorrhizal fungus, *Frankia*, and not with *Rhizobia*.



### Nif Complex

Oldroyd, suggested that plants already possess much of the genetic machinery required for fixing nitrogen symbiotically. He suggested that *Rhizobial* symbiosis has arisen three times in legumes as well as in *Parasponia*, and the association of *Casuarina* with *Frankia* are some evidences to provide the hope that in days to come cereals and other non-legume plants may be induced to nodulate and fix their own nitrogen (Oldroyd, 2007; O'Neil, 2007). Understanding of the complexity of the engineering process and the signaling mechanism between the plant and the bacterium may be helpful for development of such construct, especially in plant species like tobacco and *Arabidopsis*, which can easily be transformed.

Two processes are required for effective nitrogen fixation symbiotically. The first is to induce nodule meristem tissue to form nodules containing leghaemoglobin. That is rather easy, because development processes involving the turning on of auxins and cytokinins at the right time, are conserved across plants. The other, more difficult, challenge is to successfully induce bacterial infection, which involves the formation and penetration of infection threads leading to the development of nodules.

### Amide and Ureide Synthesis in Legumes

Ammonia is the first stable product of  $N_2$  fixation in legume nodules (Bergersen, 1965). It is excreted into the host cell cytosol, where it is assimilated and used in the synthesis of organic nitrogen for transport. Based on the products used for transport,  $N_2$  fixing legumes have been classified into two, i.e. amide exporters, and ureide-exporters. The amide exporters transport asparagine, glutamine or 4-methylene glutamine and generally belong to the tribes Viciaeae, Genisteae and Trifolieae, while ureide exporters transport either allantoin (ALN) and allantoic acid (ALA) or citruline, and are the members of tribe Phaseolae. Allantoin and allantoic acid accounts for about 60-90 per cent of the total N in the xylem sap of many tropical legumes including soybean, cowpea, garden beans, pigeonpea and other legumes grown symbiotically. These legumes contain very high levels of ureides in stems, leaves and developing fruits, because deposition occurs in these parts after translocation from xylem. Seeds also contain ureides and in some species their levels increase sharply following germination, thus providing a transportable and readily metabolized nitrogen source for seedling growth.

Synthesis of ureides in nodule is closely associated with the process of nitrogen fixation, as it is observed that ureides are rapidly labeled when nodules are exposure to  $^{15}N_2$ . Moreover, nodulated legumes contain higher concentration of ureides than non-nodulated legumes. Presence of nitrate or ammonium in the rooting medium decreases the content of ureides in xylem sap of legumes of tropical region. Such treatments also decrease nodule mass and  $N_2$  fixing activity in such legume plants, indicating that



ureides synthesized in nodules are the primary products of recent N<sub>2</sub> fixation.

### Physiological Significance of Ureides

The ureides are more efficient forms of N. In ureides, the C:N ratio is one, whereas in amides it is two. The ureides produced are more efficient in use of photoassimilates compared to amides. Cowpea (ureides producer) uses 5.5 g C g<sup>-1</sup> N fixed, while lupine (amide producer) consumes 6.9 g C g<sup>-1</sup> N fixed. In terms of ATP consumption also ureides are least expensive (requires ~6 ATP N<sup>-1</sup>) compared to the production of other nitrogenous organic compounds, viz. for organic compounds (requires ~9 ATP N<sup>-1</sup>) and citruline (requires ~3 ATP N<sup>-1</sup>). The ureide producing plants have the ability to recapture much of the energy costs associated with purine synthesis by coupling purine oxidation and other associated reactions to the reduction of NAD(P)<sup>+</sup>. The carbon skeletons associated with these ureides are highly oxidized and; therefore, the costs of synthesis of these compounds are quite low. Ureides are less hydrated than amides, hence are better suited for storage in plants. Ureide storage may have an advantage in special situations where photosynthetic and/or sink activity is affected; where storing N in the form of ureides may help in coordinating the rate of protein synthesis in relation to the availability of carbon skeletons from photosynthesis. The molar concentration of amides in the xylem is several folds higher than the corresponding concentration of ALN and ALA in the tropical legumes and, therefore, the water-use efficiency for N export is higher for amide exporters. Before assimilation ureides are degraded to NH<sub>4</sub><sup>+</sup> and CO<sub>2</sub>. The CO<sub>2</sub> released may be re-fixed by RuBISCO and/or by PEP-carboxylase. Thus, ureides may help in raising the intra-cellular level of CO<sub>2</sub> which in turn may optimize photosynthetic rate in plant. The PEP-carboxylase activity is much higher in amide exporters than in ureide exporters.

### FACTORS AFFECTING SYMBIOTIC NITROGEN FIXATION

Symbiotic N<sub>2</sub> fixation is dependent on various factors, viz. the host genotype, *Rhizobium* strain, interaction of *Rhizobium* strain with soil and climatic factors, and environmental conditions (Bordeleau and Prevost, 1994). All the stages of symbiosis, including pre-infection stages, are affected by environmental conditions and growth stage of plant. The amount of nitrogen fixed by certain legume-*Rhizobium* association may vary according to growing conditions of legume. Some legumes are especially sensitive to stressful environments, whereas symbiotic N<sub>2</sub> fixation requires vigorous plant growth. Typical environmental stresses faced by legumes are changes in rhizospheric atmosphere, water stress, salinity, etc. Effect of such factors on nitrogen fixation are described below

### Effect of Salt Stress on Symbiotic Nitrogen Fixation

Salt stress is known to depress greatly the growth and symbiotic performance of nodulated legumes. It is well known that soil salinity is one of the major constraints in agriculture in many regions of the world (Serrano and Glaxiola, 1994). According to Elsheik and Wood (1990), nodulation and nitrogen fixation are apparently more sensitive to salt than the plant growth. Same authors have reported that nitrogen fixation in indeterminate nodules is more tolerant to salt stress than that in determinate nodules (Bordeleau and Prevost, 1994; Sinclair and Serraj, 1995). Unsuccessful symbiosis under salt stresses may be due to failure in infection process due to effect of salinity on the establishment of *Rhizobia* (Rai and Prasad, 1983; Singleton and Bohlool, 1983). Tu (1981) attributed the inhibitory effect of salinity on soybean nodulation to decrease in *Rhizobial* colonization and shrinkage of root hairs. Sprent and Zahran (1988) showed that both salinity and drought, which involve changes in plant water potential, inhibit the expansion and curling of root hairs and reduce the number of nodules in fababean. Nodule formation in chickpea is adversely affected by even low levels of salinity (Elsheik and Wood, 1990).

Saline conditions lead to rapid stomatal closure, which affect the level of photosynthesis in *Phaseolus* sp (Seemann and Critchley, 1985). It has been proposed that a shortage in carbohydrate supply to the nodules limits N<sub>2</sub> fixation capacity of bacterioids from salt stressed alfalfa plants (Bekki *et al.*, 1987). However, salinity is known to boost the nodular carbohydrate content, and sucrose is reported to be the predominant carbohydrate in legume root nodules (Fougere *et al.*, 1991; Gordon *et al.*, 1997; Soussi *et al.*, 1998). Therefore, it is suggested that the decline in nitrogen fixation under saline condition is not caused directly by the lack of photosynthates. Sucrose is metabolized to produce dicarboxylic acid, mainly malate, which is preferred respiratory substrate for bacterioids (Kim and Copeland, 1996). Malate concentration reportedly diminishes with salt stress (Delgado *et al.*, 1993; Heckman *et al.*, 1989). The decrease in malate concentration indicates that the utilization of carbohydrates within nodules is inhibited during salt stress. Therefore, malate deprivation of bacterioids could be an important mechanism for the adverse effect of salt stress on N<sub>2</sub> fixation capacity.

Salt stress significantly reduces the leghaemoglobin (Lb) content, as well as the Lb/total soluble protein ratio in pea nodules. A decrease of 50% in the Lb content has been correlated with 70% loss in acetylene reduction activity as a result of salt stress (Delgado *et al.*, 1993). Delgado *et al.* (1994) suggested that a decline in N<sub>2</sub> fixation activity during severe salt stress may be due to the drop in leghaemoglobin content and bacterioid respiration. Salt stress is associated with a decrease in nodule permeability to oxygen diffusion (Serraj *et al.*, 1994; Farnandez-Fascual *et al.*, 1996). On the other hand, a stimulation of fermentation



metabolism in nodules, probably due to lower oxygen concentration, has been reported by Irigoyen *et al.* (1992). The accumulation of some organic solutes under saline conditions has been considered as an adaptation of plants against osmotic stress (Fougere *et al.*, 1991; Delauney and Verma, 1993). It has been suggested that proline, which is accumulated in nodules subjected to osmotic stress, could be utilized as an energy source for N<sub>2</sub> fixation (Kohls *et al.*, 1994; Pederson *et al.*, 1996). However, the correlation between salt concentration and concentration of these compounds is generally poor (Cordovilla *et al.*, 1996).

### Effect of Drought on Symbiotic Nitrogen Fixation

Both establishment as well as ability of the legume-*Rhizobium* symbiosis is extremely sensitive to drought stress. Consequently, legume productivity is likely to be depressed greatly both by intermittent drought and by terminal drought. The intermittent drought may occur at any time during the growing season when rainfall is inadequate and terminal drought occurs when stored soil moisture is depleted resulting in crop senescence. Symbiotic N<sub>2</sub>-fixation in legumes is also highly sensitive to soil water deficiency. Typical environmental stresses faced by legume nodules and their symbiotic partner (*Rhizobium*) affect nitrogen fixing ability (Walsh, 1995). Soil moisture deficiency has a pronounced effect on N<sub>2</sub>-fixation because nodule initiation, nodule growth, and nitrogenase activity are more sensitive to water stress than general root and shoot growth and metabolism (Graham, 1994). When nitrogen fixing legumes are subjected to water stress, it is not very much certain that which of the functions of the stressed plant actually affects the nodule formation and its functions (Streeter, 1993). The effect could be due to: (i) reduced photosynthesis, consequently reduced availability of carbohydrates, (ii) less water for the transport of N-products away from the nodule, (iii) some direct effects on nodule permeability, and (iv) alteration in nodule metabolic activity. The response of nodulation and N<sub>2</sub>-fixation to water stress depends on the growth stage of the plants. It is reported that water stress imposed during vegetative growth has been more detrimental to nodulation and nitrogen fixation than that imposed during the reproduction stage (Peña-Cabriaes and Castellanos, 1993). Under drought there is accumulation of sucrose in nodules, which is attributed due to the diminished activity of enzymes involved in sucrose breakdown (Gonzalez *et al.*, 1995).

There is a direct correlation between decreased nodule water potential and the decline in nitrogenase activity (Pankhurst and Sprent, 1975). It has been suggested that water stress acts directly on nodule activity by decreasing nitrogenase linked respiration (Durand *et al.*, 1987). Purcell and Sinclair (1995) showed changes in nodule permeability under water deficit in soybean, as a consequence there was reduced nodule respiration, and such changes have been directly related to the export of nitrogen components (Walsh, 1995). It is also observed that in legume species with



indeterminate type of nodules growth, such as in pea, when subjected to progressive water stress had a marked inhibition in their ability to reduce acetylene. Such inhibition in nitrogenase activity (in terms of acetylene reduction) often correlates with an increase in resistance of oxygen diffusion barrier of the nodule cortex (Gonzalez *et al.*, 1995). For legume crops with determinate type of nodules growth, such as in soybean, Diazdel and Layzell (1995) found that internal  $O_2$  concentration remained quite high in mildly stressed nodules, while Hunt and Layzell (1993) and Diazdel *et al.* (1994) reported that most of the reduction in nitrogenase activity could not be restored by raising the external  $O_2$  concentration. This implies that the nodules of water stressed plants no longer had the metabolic capacity to support  $N_2$  fixation even in the presence of sufficient oxygen. Purcell and Sinclair (1995) found that nitrogenase activity is affected prior to any detectable change in nodule permeability. In an experiment using PEG to impose a severe and rapid water stress, they suggested that factors other than gas permeability might be involved in the initial decline in the nitrogenase activity in nodules under moisture stress. However, Serraj and Sinclair (1996) suggested that the initial effect is due to oxygen limitation with a secondary metabolic limitation occurring after 24 hours.

Lower rates of water movement out of the nodule during drought stress may restrict the export of products of  $N_2$  fixation, thus inhibiting nitrogenase activity via feedback mechanism. Oti-Boateng and Salisbury (1993) suggested a feed back control of nodule activity that was mediated through the pool of soluble N in the plant. Parsons *et al.* (1993) developed this concept further by suggesting that nodule formation, nitrogenase activity and nodule permeability to oxygen might be controlled by the concentration of reduced nitrogenous compounds entering the nodules through the phloem. Inhibition of nitrogenase activity by drought stress could be explained in terms of product inhibition of the enzyme as an efficient feedback regulation mechanism triggered by decreased N demand of the plant (Schubert *et al.*, 1995). Legume species that transported high concentration of ureides (allantoin and allantoic acid) are more drought sensitive compared to species with low or no ureides (amide transporters) (Sinclair and Serraj, 1995). The feedback in those legumes that export ureides from the nodules seems to be especially aggravated by the accumulation of ureides in the plant. However, specific feedback signal compound or mode of action of this feedback is not yet resolved.

The occurrence of *Rhizobial* populations in desert soils, and effective nodulation of legumes growing therein, emphasizes the fact that *Rhizobia* can also exist in soils with limiting moisture levels.

### Effect of Waterlogging on Symbiotic Nitrogen Fixation

Induced soil anaerobiosis is harmful to nodule formation and function in several legume species (Hong *et al.*, 1977; Bisseling *et al.*, 1980; Turner *et al.*, 1983; Huang and La Rue, 1985). Waterlogging inhibits the nitrogen



fixing activities of nodule (Sung *et al.*, 1993). This might be caused by the decreased synthesis of nitrogenase by the bacterioids (Bisseling *et al.*, 1980) or by curtailed carbohydrate metabolism of host tissue in the nodule (Huang and La Rue, 1985). Bisseling *et al.* (1980) found that production of the iron protein of the nitrogenase complex is repressed under waterlogging. Reduced specific nodule activities (SNA) is partly due to concomitant decline in content of leghaemoglobin (Siung, 1993) that facilitates the oxygen diffusion from the nodule surface to the bacterioid. Buttery (1987) reported that soybean plants grown on nitrate were less sensitive to a 30 day flooding stress than plants relying on N<sub>2</sub> fixation. The positive effect of nitrate on flooding tolerance may be due to a lesser O<sub>2</sub> requirement for nitrate uptake and assimilation compared with N<sub>2</sub> fixation, which may mimic N deficiency and subsequent decrease in biomass accumulation (Bacanamwo and Purcell, 1999). It is indicated that improving N availability under flooding or selecting for genotypes that maintain high rates of N acquisition under flooding may be effective strategies for improving tolerance to flooding stress.

### Effect of Temperature on Symbiotic Nitrogen Fixation

**High temperature:** High root zone temperatures have been shown to strongly affect bacterial infection and N<sub>2</sub> fixation in several legume species, including soybean (Munevar and Wollum, 1982), clover (Possingham *et al.*, 1965), guar (Arayangkoon *et al.*, 1990), peanut (Kishinevsky *et al.*, 1992), cowpea (Philpotts, 1967; Rainbird *et al.*, 1983) and beans (Hungria and Franco, 1993; Piha and Munns, 1987; Panwar *et al.*, 1988). Elevated temperatures may delay nodule initiation and development and interfere with nodule structure and functioning in temperate legumes, whereas in tropical legumes elevated ambient temperature mainly affects N<sub>2</sub> fixation efficiency. The effect of high temperature depends on plant species, cultivar and *Rhizobium* strain. Hernandez-Armenta *et al.* (1989) found that transferring nodulated bean plants from 26 to 35 °C daily temperatures markedly inhibited N<sub>2</sub> fixation. Soybean plants appear somewhat more tolerant to high temperature where nitrogen fixation is severely inhibited by day time temperatures greater than 41 °C (La Favre and Eaglesham, 1987). Root temperatures above 30 °C have been shown to reduce nitrogenase activity in peanut (Nambiar and Dart, 1983). *Bradyrhizobium* symbiosis in peanut is completely inhibited when root temperature is 40 °C (Kishinevsky *et al.*, 1992). The effect was both due to failure of nodulation and inability of the nodule function at this temperature even when nodules were formed.

**Low temperature:** Low temperatures delay root infection of root hairs with *Rhizobium*, and decrease nodulation and nitrogenase activity (Waughman, 1977). Low temperature is also shown to have adverse affect on nodule development in *Trifolium* spp., *Lotus* spp., *Stylosanthes* spp. and *Vicia faba*, without altering the sequence of anatomical changes (Fyson and Sprent, 1982). Effective nodule development and nitrogenase activity



are completely inhibited in alfalfa at 8°C (Cralle and Heichel, 1982). Suboptimal root zone temperature conditions decrease N<sub>2</sub> fixation activity by directly decreasing the activity of the nitrogenase enzyme complex (Layzell *et al.*, 1984) and by suppressing and/or delaying root infection and nodulation (Walsh and Layzell, 1986). The greater degree of sensitivity to low root zone temperature below 17.5°C is reported to be due to events related to or occurring before infection thread penetration to the base of the root hair (Zhang and Smith, 1994). Lie (1974) and Fyson and Sprent (1982) concluded that low temperatures delay bacterioid tissue formation. The increased individual nodule mass and reduced specific nodule activity, observed at low temperatures, have been due to inhibition of nodule cell differentiation and bacterioid tissue development (Fyson and Sprent, 1982; Pankhurst and Layzell, 1984). In soybean *Bradyrhizobium japonicum* symbiosis at suboptimal root zone temperatures slowed down nodule development by disruption of signal exchange between the host plant and *Bradyrhizobium* (Zhang and Smith, 1997). The prior incubation of *Bradyrhizobium* with genistein has been shown to increase nodule number at lower root zone temperatures, but the effect of genistein application on nodule number and N<sub>2</sub> fixation decreases with increasing root zone temperature (Zhang and Smith, 1995). Lower temperature resulted in marked reduction in nodule efficiency and acetylene reduction assay per nodule dry weight in soybean. More of the N fixed at lower root temperature accumulates in the root, presumably due to decreased N translocation (Lynch and Smith, 1983). Cultivars vary in their response to low temperature (Rennie and Kemp, 1981). Bean variety Kentwood failed to nodulate at 10°C and took 32 days to initiate nodulation at 12°C, while cultivar Aurora nodulated in 23 and 21 days at 10 and 12°C, respectively. Strain differences in nodulating ability at low temperatures have been shown between arctic and temperature zone *Rhizobia* (Ek-Jander and Fahraeus, 1971; Schulman *et al.*, 1988).

### Effect of Soil Acidity on Symbiotic Nitrogen Fixation

Soil acidity affects all aspects of nodulation and nitrogen fixation from survival and multiplication of the *Rhizobia* in the soil, through infection and nodulation to nitrogen fixation. The failure of legumes to nodulate under acidic soil condition is common, especially in soils with pH less than 5.0. The inability of some *Rhizobia* to persist under such conditions is one of the causes of failure of nodulation (Graham *et al.*, 1982; Lowendorf and Alexander, 1983). Pijnenborg *et al.* (1991) suggested that the major factor contributing to the nodulation failure and the stunted growth of lucerne in soils with pH below 6.0 is the poor survival of *R. meliloti*. However, chickpea root nodule bacteria appeared to survive quite well under acidity, even down to a soil pH of 4.2 and this was further shown by the enhanced lateral nodulation, but the limiting factor is thought to be the inability of the host plant to tolerate



acidic soil pH (Scott and Howeson, 2000). Species of *Rhizobium* were known to differ in their tolerance to soil acidity. Slow growing *Bradyrhizobium* strains being generally more tolerant to acidic pH than fast growing, especially *R. meliloti* (Munns and Keyser, 1981). van Rossum *et al.* (1994) observed that the soil acidity enhances nodulation in groundnut, particularly when nodulation was caused by the indigenous *Bradyrhizobium* population. However, the enhancement is found to be affected by groundnut cultivars. The acid tolerant and sensitive cultivars differed in their content and concentration of root exudates, which might be involved in the relative performance of the cultivars under acidic soil pH (Raman, 1992).

### Effect of Elevated Atmospheric CO<sub>2</sub> on Symbiotic Nitrogen Fixation

Elevated CO<sub>2</sub> is likely to affect carbon cycling and crop productivity by stimulating photosynthesis. Some authors (Hartwig *et al.*, 1996) postulated that legumes, which can fix atmospheric N<sub>2</sub>, would have an advantage over other plants. Legumes could respond to a potential C:N imbalance, caused by elevated CO<sub>2</sub> by introducing N through symbiotic N<sub>2</sub> fixation. One obvious hypothesis in predicting the response of symbiotic N<sub>2</sub> fixation to elevated atmospheric CO<sub>2</sub> would be that as the rate of photosynthesis increases more photosynthates would be delivered to the nodules and thus nitrogenase activity increases (Hardy and Havelka, 1976). The long term increase of total nitrogenase activity under elevated CO<sub>2</sub> would be due to increase in the number and in the individual weight of the nodules, but under such treatment the nitrogenase activity per unit nodule dry weight has not been greater than that in the control (Finn and Brum, 1982; Ryle *et al.*, 1992). It is given that elevated CO<sub>2</sub> enhanced plant growth might result in an increased N-sink strength (Ingestad, 1982), as a result nitrogenase activity is probably upregulated to meet out the increased N demand (Hartwig and Nosberger, 1994; Hartwig *et al.*, 1994; Oti-Boateng and Salisbury, 1993; Parsons *et al.*, 1993).

Low rhizospheric CO<sub>2</sub> concentration (below 100 ppm) results in significant decline in nitrogenase activity in legume nodules (Bethenod *et al.*, 1984). However, increasing the partial pressure of CO<sub>2</sub> (pCO<sub>2</sub>) in the rhizosphere above ambient did not stimulate the nitrogenase activity in soybean. Therefore, direct affects of altered rhizospheric CO<sub>2</sub> on nitrogenase activity are unlikely. It is well known that nitrogenase activity is very much limited by oxygen concentration rather than by CO<sub>2</sub> concentration (Hunt and Layzell, 1993).

Mungbean sustained its photosynthetic efficiency under elevated CO<sub>2</sub>. There was no down regulation of photosynthesis and, instead, showed an up regulation of photosynthesis as it accumulated excess assimilates as starch (Sharma and Ghildiyal, 1998; Sharma *et al.*, 2004). However, under such treatments increase in nodule numbers and nodules dry weight are reported to be associated with a higher photosynthetic



rate (Sharma *et al.*, 2004). Higher nitrogenase activity is also observed to be associated with higher photosynthesis rate.

Ghildiyal *et al.* (2001) and Pandurangan *et al.* (2006) concluded that the leaf starch accumulating crops, such as mungbean and sunflower, can take advantage of higher level of substrate (elevated CO<sub>2</sub>) in future as compared to leaf sugar accumulating crops like rice and wheat.

### Effect of Agrochemicals on Symbiotic Nitrogen Fixation

The use of pesticides has become an essential part of agriculture. Pesticides have different effects on symbiotic systems. For example, the fungicide carbendazim has been found to have no significant effect on number of nodules in cowpea, but it increases the fresh nodule weight and total N content (Singh *et al.*, 1986). Yet, the same compound decreased the number of *Bradyrhizobium japonicum* surviving on soybean seeds and decreases nodulation and yield in this crop in field. But, when associated with oxine copper, the carbendazim had no detrimental effect on *B. japonicum* or soybean growth (Catroux and Arnand, 1991). Golebiowska *et al.* (1967) reported that *Rhizobium* strains showed different sensitivities to the fungicide thiram. Carbendazim and thiram had no negative or positive effects on chickpea nodulation (Welty *et al.*, 1988).

The insecticide dimethoate (1%) reduces nodule number by 63% in black gram and 64% in pea. Leghaemoglobin concentration, nitrogenase activity and size of the bacterial region are also reduced by the higher rates of dimethoate application (Soam and Agrawal, 1989). At lower concentration, the insecticide phorate enhances the activity of nitrogenase, but inhibits it at higher concentration (Singh and Mathur, 1989). The stimulation response of phorate at the lower doses on nitrogenase activity is consistent with the work of Nayak and Rao (1980). The higher concentration of phorate causes a drastic fall in the activity of nitrogenase, indicating that either it is toxic to the bacteriod and/or affecting the permeability of the nodule. The increase in nitrogenase activity at lower concentration of phorate has been the consequence of the increased concentration of gibberellins (Singh *et al.*, 1982), which stimulates the nitrogenase activity (Sehon *et al.*, 1985). Some data, concerning stimulation of nodulation and N<sub>2</sub> fixation in *Vicia faba* by some herbicides were reported by Abdel-Gaffar (1987), who concluded that terbutryn (2.5 L ha<sup>-1</sup>) significantly increased dry weight of nodules and trifluralin (4.76 L ha<sup>-1</sup>, applied 21 days after sowing), stimulated plant growth and total nitrogen fixed. Some herbicides inhibit growth, deform stems and roots and may kill the *Rhizobia* present in the soil, thus reducing nodulation and nitrogen fixation (Hamdi, 1982; Bollich *et al.*, 1984). However, the stimulatory or inhibitory effects of herbicides on N<sub>2</sub> fixation are dependent on herbicide concentrations, site of action and their mechanism of action in plants.



## REFERENCES

- Abdel-Goffar, S. 1987. Factors affecting nitrogen fixation and yield of fababean under Egyptian field condition: A review. *Arid Sci. Res. Rehabit.* **1**: 65-67.
- Arayamgkoon, T.; Schemberg, H. A. and Heaver, R. W. 1990. Nodulation and N fixation of guar at high root temperature. *Plant Soil.* **126**: 209-13.
- Bacanamwo, M. and Purcell, L. C. 1999. Soybean dry matter and N accumulation response to flooding stress, N sources and hypoxia. *J. Exp. Bot.* **50**: 689-96.
- Balchandar, D. and Nagarjuna, P. 1999. Dual inoculation of *vesicular arbuscular* mycorrhiza and rhizobium in green gram. *Legume Res.* **19**: 33-39.
- Bathenod, O.; Prionl, J. L and Deroche, M.E. 1984. Short term inhibition of acetylene reduction activity by low CO<sub>2</sub> concentration around the nodulated roots of various legumes. *Physiol. Veg.* **22**: 565-70.
- Bekki, A.; Trinchant, J. C. and Rigaud, J. 1987. Nitrogen fixation (C<sub>2</sub>H<sub>2</sub> reduction) by *Medicago* nodules and bacteroides under sodium chloride stress. *Plant Physiol.* **71**: 61-67.
- Bergersen, F. J. 1965. Root Nodules of Legumes: Structure and Function. Research Studies Press, Chichester.
- Bethenod, O.; Van Stavern, W. and van Kammen, A. 1984. The effect of waterlogging on the synthesis of nitrogen compounds in bacteroid of *Rhizobium leguminosarum* in root nodules of *Pisum sativum*. *Biochem. Biophy Res. Comm.* **93**: 687-93.
- Bisseling, T.; Van Stavern, W. and Van Kamman, A. 1980. The effect of water logging on the synthesis of nitrogen components in bacteroid of *Rhizobium leguminoserum* in root nodules of *Pisum sativum*. *Biochem. Biophys. Res. Comm.* **93**: 687-93.
- Bollich, P. K.; Duningam, E. P.; Hager, T. R. and Kitchen, L. M. 1984. Effect of herbicides on nodulation, nitrogen fixation and seed yield of soybean in Louisiana. *Louisiana Exp. Station Bull.* **762**: 3-15.
- Bordeleau, L. M. and Prevost, D. 1994. Nodulation and nitrogen fixation in extreme environments. *Plant Soil.* **161**: 115-25.
- Buttery, B. R. 1987. Some effects of water logging and supply of combined nitrogen on soybean growth. *Canadian J. Plant Sci.* **67**: 69-77.
- Catroux, G. and Arnand, F. 1991. Compatibility of pest inoculants with some soybean seed applied fungicides and microgranular insecticides. *Toxicol. Environ. Chem.* **30**: 229-39.
- Challaham, D. M. and Torray, J. C. 1981. The structural basis for infection of root hairs of *Trifolium refrens* by rhizobium. *Canadian J. Bot.* **59**: 1647-64.
- Cordovilla, M. P.; Ligerio, F. and Luch, C. 1996. Growth and nitrogen assimilation

- in nodules in response to nitrate levels in *Vicia faba* under salt stress. *J. Exp. Bot.* **17**: 203-10.
- Cralle, H. T. and Heichel, G. H. 1982. Temperature and chilling sensitivity of nodule nitrogenase activity of unhardened alfalfa. *Crop Sci.* **21**: 300-04.
- Delauney, A. J. and Verma, D. P. S. 1993. Proline biosynthesis and osmoregulation in plants. *The Plant J.* **4**: 215-23.
- Delgado, M. J.; Garrido, J. M.; Ligeró, F. and Lluch, C. 1993. Nitrogen fixation and carbon metabolism by nodules and bacteroids of pea plants under sodium chloride stress. *Physiol. Plant.* **89**: 824-29.
- Delgado, M. J.; Ligeró, F. and Lluch, C. 1994. Effect of salt stress on growth and nitrogen fixation by pea, fababeans, common beans and soybean plants. *Soil Biol. Biochem.* **28**: 371-76.
- Diazdel, C. L. and Layzell, D. B. 1995. Drought stress, permeability to O<sub>2</sub> diffusion and the respiratory kinetics of soybean root nodules. *Plant Physiol.* **107**: 1187-94.
- Diazdell Castillo, L.; Hunt, S.; Layzell, D. B. 1994. The role of oxygen in the regulation of nitrogenase activity in drought stressed soybean nodules. *Plant Physiol.* **106**: 949-55.
- Dongre, A. B.; Lodha, M. L.; Prakash, N. and Mehta, S. L. 1985. Ultra structure studies of infection mechanism of *Rhizobium* strain 6050 in groundnut mutant. *Indian J. Exp. Biol.* **23**: 387-92.
- Durand, J. L.; Sheehy, J. D. and Minchin, F. R. 1987. Nitrogenase activity, photosynthesis and nodule water potential in soybean plants experiencing water deprivations. *J. Exp. Bot.* **38**: 311-21.
- Ek-Jander, J. and Fahraeus, G. 1971. Adaptation of *Rhizobium* to subarctic environment in Scandinavia. *Plant Sci. (spl. vol.)*: 129-21.
- Elsheik, E. A. E. and Wood, M. 1990. Effect of salinity on growth, nodulation and nitrogen yield of chickpea. *J. Exp. Bot.* **41**: 1263-69.
- Farnandez-Fascual, M.; De Lorenzo, C.; De Flip, M. R.; Rajalakshmi, S.; Gordon, A. J.; Thomas, B. J. and Minchin, F. R. 1996. Possible reason for relative salt stress tolerance in nodules of white lupin cv. Multilopa. *J. Exp. Bot.* **41**: 1709-16.
- Finn, G. A. and Brum, W. A. 1982. Effect of atmospheric CO<sub>2</sub> enrichment on growth, non-structural carbohydrate content and root nodule activity in soybean. *Plant Physiol.* **69**: 327-31.
- Fougere, F.; Le Rudulier, D. and Streeter, J. G. 1991. Effect of salt stress on amino acid, organic acid and carbohydrate composition of roots, bacteroids and cytosol of alfalfa. *Plant Physiol.* **96**: 1228-36.
- Fyson, A. and Sprent, J. L. 1982. The development of primary root nodules on *Vicia faba* grown at two room temperatures. *Ann. Bot.* **50**: 681-92.



- Ghildiyal, M. C.; Rafiq, S. and Sharma Natu, P. 2001. Photosynthetic accumulation of CO<sub>2</sub> in relation to leaf saccharides constituents in wheat and sunflower. *Phytosynthetica*, **39**: 447-52.
- Golebiowska, J.; Kaszsubiak, H. and Pajonska, M. 1967. Adaptation of *Rhizobium* to thiram. *Acta. Microbiol. Pol.*, **16**: 153-58.
- Gonzalez. E. M.; Gordon, A. J.; James, C. L. and Arres-Igor, C. 1995. The role sucrose synthase in the response of soyabean nodules to drought. *J. Exp. Bot.* **46**: 1515-23.
- Gordon, A. J.; Minchin, F. R.; Skot, L. and James, C. L. 1997. Stress induced declines in soybean N fixation are related to nodule sucrose synthase activity. *Plant Physiol.* **114**: 937-46.
- Graham, P. H. 1994. Stress tolerance in *Rhizobium* and *Bradyrhizobium* and nodulation under adverse soil condition. *Canadian J. Microbiol.* **38**: 475 -84.
- Graham, P. H.; Viteri, S. E. and Mackoe, F. 1982. Variation in acid soil tolerance among strains of *Rhizobium phaseoli*. *Field Crop Res.* **5**: 121-28.
- Gupta, S. C. and Namdeo, S. L. 1996. Effect of rhizobium strains on symbiotic traits and grain yield of chickpeas. *Indian J. Pulses Res.* **9**: 94-95.
- Hamdi, Y. A. 1982. Symbiotic N<sub>2</sub> fixation in fababean. In: *Fababean Improvement*. Hawtin G. and Webb C., (Eds). The Hoque. The Netherlands. Martinus Nijhoff Pub, pp. 127-38.
- Hardy, R. W. F. and Havelka, U. D. 1976. Photosynthate as major factor limiting nitrogen fixation by field grown legumes with emphasis on soybean. In: *Symbiotic N<sub>2</sub> Fixation*. Nutman P. S., (Ed). Cambridge Univ. Press, UK, pp. 421- 36.
- Hartwig, U. A. and Norberger, J. 1994. What triggers the nodulation of nitrogenase activity in forage legumes nodules after defoliation. *Plant Soil.* **169**: 109-14.
- Hartwig, U. A.; Heim, I.; Lusher, A. and Nosberger, J. 1994. The nitrogen sink is in the regulation of nitrogenase activity in white clover after defoliation. *Physiol. Plant.* **92**: 375-82.
- Hartwig, U. A.; Zanetti, S.; Hebeisen, T.; Lusher, A.; Frehner, M.; Fisher, B.; Van Kessel, C. A.; Hendry, G. R.; Blum, H. and Hosberger, J. 1996. Symbiotic nitrogen fixation; one key to understand the response of temperate grassland ecosystem to elevated CO<sub>2</sub>. In: *Carbon di oxide, Population and Communities*. Kroner C. and Bazzaz F., (Eds). Academic Press, San Diego, pp. 253-64.
- Heckman, M. O.; Drevon, J. J.; Sanglio, P. and Salsac, L. 1989. Effect of oxygen and malate on NO<sub>3</sub><sup>-</sup> inhibition of nitrogenase in soybean nodules. *Plant Physiol.* **90**: 224-29.
- Hernandez Armenta, R.; Wien, H. C. and Egelsham, A. R. J. 1989. Maximum temperature for nitrogen fixation in common bean. *Crop Sci.* **29**: 1260-65.

- Hong, T. D.; Minchin, F. R. and Summerfield, R. J. 1977. Recovery of nodulated cowpea plant from waterlogging during vegetative growth. *Plant Soil*. **48**: 661-72.
- Huang, C. Y. and La Rue, J. A. 1985. Effect of waterlogging on nitrogen fixation and carbohydrate metabolism in nodules of soybean plants. *Proc. Natl. Sci. Counc. B. Roc.* **9**: 82-88.
- Hungaria, M. and Franco, A. A. 1993. Effect of high temperature on nodulation and N<sub>2</sub> fixation by *Phaseolus vulgaris*. *Plant Sci.* **149**: 95-102.
- Hunt, S. and Layzell, D. B. 1993. Gas exchange of legume nodules and the regulation of nitrogenase activity. *Ann. Rev. Plant Physiol Mole Biol.* **44**: 483-511.
- Ingestad, T. 1982. Relative addition rate and external conditions driving variables used in plant nutrition research. *Plant Cell Environ.* **5**: 443-53.
- Irigoyen, J. J.; Emerich, D. W. and Sanchez-Diaz, M. 1992. Phospho enol pyruvate carboxylase and malate and alcohol dehydrogenase activities in alfalfa (*Medicago sativa*) nodules under stress. *Physiol. Plant.* **84**: 61-66.
- John Innes. 2007. Nodding acquaintance between legumes and bacteria. [www.biotechnews.com.au/index.php/id\\_427199777;fp;4;fpid;2](http://www.biotechnews.com.au/index.php/id_427199777;fp;4;fpid;2).
- Kennedy, I. R. 1997. BNF: An energy costly process? In: *BNF: The Global Change and Future Need at Rockefeller Foundation Bellogio Conference Centre, Lake Como, Italy, April, 18-22*, pp. 224.
- Kim, S. A. and Copeland, L. 1996. Enzymes of poly-β-hydroxybutyrate metabolism in soybean and chickpea bacteroids. *Appl. Environ. Microbiol.* **62**: 4186-90.
- Kishinevsky, B. D.; Sen, D. and Weaver, R. W. 1992. Effect of high root temperature on *Bradyrhizobium*-peanut symbiosis. *Plant Soil*. **143**: 275-82.
- Kohls, S. J.; van Kessel, C.; Baker, D. D.; Grigal, D. F. and Lawrence, B. D. 1994. Assessment of N<sub>2</sub> fixation and N cycling by *Dryas* along chrono sequence within the forelands of the Athabasca Glacier, Canada. *Soil Biol. Biochem.* **26**: 623-32.
- La Favre, A. K. and Eaglesham, A. R. J. 1987. Effect of high soil temperatures and starter nitrogen on the growth and nodulation of soybean. *Crop Sci.* **27**: 742-45.
- Layzell, D. B.; Rochmann, P. and Canvar, D. T. 1984. Low temperature and nitrogenase activity in soybean. *Canadian J. Bot.* **62**: 665-71.
- Lie, T. A. 1974. Environmental effects on nodulation and symbiotic nitrogen fixation. In: *The Biology of Nitrogen Fixation*. Quisbel A. (Ed) North Holland Publishing House Inc. Amsterdam, pp. 555-82.
- Lowerdorf, H. S. and Alexander, M. 1983. The identification of *Rhizobium phaseoli* strains that are tolerant or sensitive to soil acidity. *Applied Environ. Microbiol.* **45**: 737-42.



- Lynch, D. H. and Smith, D. L. 1983. Soybean nodulation and nitrogen fixation as affected by exposure to a low root zone temperature. *Physiol. Plant.* **88**: 212-20
- McCardell, A.; Sadowsky, M. J. and Grogan, P. B. 1993. Genetics and improvement of biological nitrogen fixation *In: Soil Microbial Ecology*. Melting, Jr F. B., (Ed.). Marcel Dekker, New York, pp. 151-76.
- Munevar, F. and Wollum, A. G. 1982. Effect of high root temperature and *Rhizobium* strain on nodulation, nitrogen fixation and growth of soybean. *Soil. Sci. Am. J.* **45**: 1113-20.
- Munns, D. N. and Keyser, H. H. 1981. Tolerance of *Rhizobia* to acidity, aluminium and phosphate. *Soil Sci. Soc. Am. J.* **34**: 519-33.
- Nambiar, P. T. C. and Dart, P. T. 1983. Factors influencing nitrogenase activity of root nodules of groundnut. *Peanut. Sci.* **10**: 26-29.
- Nayak, D. N. and Rao, V. R. 1980. Heterotrophic nitrogen fixation as influenced by pesticides. *Soil Biol. Biochem.* **12**: 1-4.
- Nutman, P. S. 1976. Symbiotic N<sub>2</sub> fixation. Cambridge Univ. Press, UK.
- O'Neil, G. 2007. Nodding acquaintance between legume and bacteria. *Australian Life Scientist.* **11**: 49. [http://www.lifescientist.com.au/article/195138/combio\\_special\\_nodding\\_acquaintance\\_between\\_legumes\\_bacteria/](http://www.lifescientist.com.au/article/195138/combio_special_nodding_acquaintance_between_legumes_bacteria/)
- Oldroyd. 2007. Nodding acquaintance between legumes. pp 3-5. Leghaemoglobin. <http://www.biotechnews.com.au/index.php/id;427199777;fp;4;fpid;2,7/3/2008>.
- Oti, Boateng C. and Salisbury, J. H. 1993. The effect of exogenous amino acid as acetylene reduction activity of *Vicia faba* cv. Frorid. *Ann. Bot.* **71**: 71-74.
- Palaniappan, S. P.; Natarajan, T. and Thulasidass, G. 1983. Effect of certain soil amendments on rhizobium legume symbiosis. *Sixth Southern Regional Conference on Microbial Inoculants*, held on 22-23 September at UAS, Bangalore, India.
- Pandurangan, V.; Sharma Natu, P.; Sreekanth, B. and Ghildiyal, M. C. 2006. Photosynthetic response of wheat and sunflower cultivars to long term exposure of elevated carbon di oxide concentration. *Photosynthetica.* **44**: 586-90.
- Pankhurst, C. E. and Layzell, D. B. 1984. The effect of bacterial strain and temperature changes on the nitrogenase activity of *Lotus pedunculatus* root nodules. *Physiol. Plant.* **62**: 404-9.
- Pankhurst, C. E. and Sprent, J. I. 1975. Effect of water stress on the respiration and nitrogen fixing activity of soybean root nodules. *J. Exp. Bot.* **26**: 287-304.
- Panwar, J. D. S. and Thakur, A. K. 1995. VAM fungi: A potential supplier of phosphorus and other micronutrients. *Farmers and Parliament*. May, 1995: pp. 23-24.

- Panwar, J. D. S.; Abbas, S.; Sita Ram and Sirohi, G. S. 1988. Effect of B A P, ethrel and stem girdling on growth and partitioning of photosynthates in Y- shaped mungbean. *Indian J. Plant Physiol.* **31**: 418- 22.
- Parson, R; Stanforth, A.; Roven, J. A. and Sprent, J. I. 1993. Nodule growth and activity may be regulated by a feed back mechanism involving phloem nitrogen. *Plant Cell Environ.* **16**: 125-36.
- Pederson, A. I.; Feldner, H. C. and Rosendahl, 1996. Effect of proline on nitrogenase activity in symbiosomes from root nodules of soybean (*Glycine max* L.) subjected to drought stress. *J. Exp. Bot.* **47**: 1533-39.
- Peña-Cabriaes, J. J. and Castellanos, J. Z. 1993. Effect of water stress on N<sub>2</sub> fixation and grain yield of *Phaseolus vulgaris* L. *Plant Soil.* **152**: 115-21.
- Philpotts, H. 1967. The effect of soil temperature on nodulation of cowpea (*Vigna sinensis*). *Aust. J. Exp. Agric. Anim. Husb.* **7**: 372-76.
- Piha M.I. and Munns D.N. 1987. Sensitivity of common bean symbiosis to high soil temperature. *Plant Sci.* **98**: 183-91.
- Pijnenborg, J. W. M.; Lie, T. A. and Zehnder, A. J. B. 1991. Nodulation of lucerne (*Medicago sativa* L.) in an acid soil: Effect of inoculum size and lime-pelleting. *Plant Soil.* **131**: 1-10.
- Possingham, J. V.; Moye, D. V. Y. and Anderson, A. J. 1965. Effect of elevated shoot and root temperature on nitrogen fixation. *Plant Physiol.* **39**: 561-63.
- Prabhakaran, J. and Srinivasan, K. 1995. Effect of rhizobium inoculation and coir dust on growth, nodulation and yield of pigeonpea. *Indian J. Agron.* **40**: 518-19.
- Purcellinitial S. and Sinclair T.R. 1995. Nodule gas exchange and water potential response to rapid imposition of water deficit. *Plant Cell Environ.* **18**: 179-87.
- Rai, R. and Prasad, V. 1983. Salinity tolerance of rhizobium mutants growth and relative efficiency of symbiotic nitrogen fixation. *Soil Biol. Biochem.* **15**: 215-19.
- Rainbird, P. M.; Atkin, C. A. and Pate, J. S. 1983. Diurnal variation in the function of cowpea nodules. *Plant Physiol.* **72**: 308-12.
- Raman, R. 1992. Effect of soil acidity factors on aspects of symbiotic nitrogen fixation of *Lens culinaris* in acid soils. *J.Gen. Appl. Microbiol.* **38** (5): 391-406.
- Rangarajan, M. and Prabhakaran, J. 1980. Screening of rhizobial strains for their effect on nodulation and seed yield of pulse crops. *National Seminar on Microbial Ecology*, held at TNAU, Coimbatore.
- Rathi, B. K.; Jain, A. K.; Kumar, S. and Panwar, J. D. S. 2009. Response of *Rhizobium* inoculation with sulphur and micronutrients on yield and yield attributes of black gram. *Legume Res.* **32**: 62-64.



- Rennie, R. J. and Kemp, G. A. 1981. Dinitrogen fixation in *Phaseolus vulgaris* at low temperature: Interaction of temperature, growth stage and time of inoculation *Can. J. Bot.* **60**: 1423-27.
- Ryle, G. J. A.; Powell, C. E. and Davidson, A. 1992. Growth of white clover, dependent on N<sub>2</sub> fixation, in elevated CO<sub>2</sub> and temperature. *Ann. Bot.* **70**: 221-28.
- Schubert, S.; Serraj, R.; Plies-Balzer, E. and Mengel, K. 1995. Effect of drought stress on growth, sugar concentrations and amino acid accumulation in N<sub>2</sub>-fixing alfalfa. *J. Plant Physiol.* **146**: 541-46.
- Schulman, H. M.; Lewis, M. C.; Tipping, E. M. and Bordeleau, L. M., 1988. Nitrogen fixation by three species of leguminosae in the Canadian high arctic tundra. *Plant Cell Environ.* **11**: 721-28.
- Scott, J. and Howeson, J. 2000. Pulse research and industry development in Western Australia. Chickpea nodulation survey. In: *Crop Updates*, pp. 32.
- Seemann, J. R. and Critchley, C. 1985. Effect of salt stress on growth, ion content, stomatal behaviour and photosynthetic capacity of salt-sensitive species, *Phaseolus vulgaris* L. *Plant Physiol.* **82**: 555-60.
- Serraj, R. and Sinclair, T. R. 1996. Inhibition of nitrogenase activity and nodule oxygen permeability by water deficit. *J. Exp. Bot.* **47**: 1067-73.
- Serraj, R.; Buhariwalha, H. K.; Sharma, K. K.; Gaur, M. P. and Crouch, J. H. 2004. Crop improvement of drought resistance in pulses: A holistic approach. *Indian J. Pulses Res.* **17**: 1-13.
- Serrano, R. and Glaxiola, R. 1994. Microbial model and salt stress tolerance in plants. *Crit. Rev. Plant Sci.* **13**: 121-38.
- Sharma Natu, Poonam and Ghildiyal, M. C. 1998. Photosynthesis under elevated CO<sub>2</sub> in species differing in source-sink relationship. CSIR Project, IARI, New Delhi
- Sharma Natu, Poonam; Vijai P. and Ghildiyal, M. C. 2004. Photosynthetic acclimation and productivity of mungbean cultivars under elevated CO<sub>2</sub> concentration. *J. Agron. Crop Sci.* **190**: 81-85.
- Sinclair, T. R and Serraj, R. 1995. Legume nitrogen fixation and drought. *Nature*: **378**: 344.
- Singh, D.P.; Rawson, H. M. and Turner, N. C. 1982. Effect of radiation, temperature and humidity on photosynthesis, transpirational water use efficiency of chickpea. *Indian. J. Plant Physiol.* **25**: 32-39.
- Singh, G. R.; Sharma, S. R. and Kumar, T. B. 1986. Effect of biloxazol, carbandazim and triademefon on nodulation and nitrogen fixation in cowpea. *Zentralbi Mikrobil.* **141**: 35-37,
- Singh, V. P. and Mathur, S. N. 1989. Studies with phorate, an organo phosphate insecticide, on growth, nodulation and some enzymes of nitrogen metabolism in black gram. *Indian J. Plant Physiol.* **32**: 314-19.

- Singleton, P. W. and Bohlool, B. B. 1983. Effect of salinity on the functional component of the *Soybean japonicum* symbiosis. *Crop Sci.* **23**: 815-18.
- Siung, F. J. M. 1993. Waterlogging effect on nodule nitrogenase and leaf nitrate reductase activity in soybean. *Field Crop Res.* **35**: 183-89.
- Smith, S. E. and Hume, D. J. 1987. Comparison of assay method of nitrogen fixation utilizing bean and soybean. *Canadian J. Plant Sci.* **67**: 11-19.
- Soam, S. K. and Agrawal, P. K. 1989. Effect of dimethoate on nodulation and nitrogenase activity of nodules in pea and black gram. *Indian J. Agric. Sci.* **59**: 824-25.
- Soussi, M.; Ocana, A. and Lluch, C. 1998. Effect of salt stress on growth, photosynthesis and nitrogen fixation in chickpea (*Cicer arietinum* L.). *J. Exp. Bot.* **49**: 1329-37.
- Sprent, J. I. and Zahran, H. H. 1988. Infection, development and functioning of nodules under drought and salinity. In: *Nitrogen Fixation by Legumes in Mediterranean Agriculture* Deck D. F. and Meatro L. A., (Eds). MartinusNijhoff Dordrecht. ISBN 90-247-2405-8, pp. 145- 51.
- Sprent, J. I. and Sprent, P. 1990. *Nitrogen Fixing Organisms*. Chapman and Hall, New York.
- Streeter, J.G. 1993. Translocation- a key factor limiting the efficiency of nitrogen fixation in legume nodules. *Physiologia Plantarum.* **87**: 616-23.
- Subbarao, N. S. 1988. *Biological Nitrogen Fixation: Recent Developments*. Oxford, & IBH, pp. 1-19.
- Sung, S.; Sheih, W. J.; Gregor, D. R. and Black, C. C. 1993. Growth, sucrose synthase, and invertase activity of developing *Phaseolus vulgaris* fruits. *Plant Cell Environ.* **17**: 419-26.
- Tu, J. C. 1981. Effect of salinity on Rhizobium-root hair interaction, nodulation and growth of soybean. *Canadian J. Plant Sci.* **61**: 231-39.
- Turner, C. B. and Sinclair, T. R. 1983. Efficient water use in crop production: Research or re- search? In: *Limitation to Water Use in Crop Plants*. Taylor H. M., (Ed). Crop Society of America, Madison, pp. 1-27.
- van Rossum, D.; Muyotcha, A.; De Hope, B. M., van Verseveld, H. W.; Stouthamer, A. H. and Boogerd, F. C. 1994. Soil acidity in relation to groundnut-*Bradyrhizobium* symbiotic performance. *Plant Soil.* **163**: 165-75.
- Walsh, K. B. 1995. Physiology of the legume nodule and its response to stress. *Soil Biol. Biochem.* **27**: 637-55.
- Walsh, K. B. and Layzel, D. B. 1986. Carbon and nitrogen assimilation and partitioning in soybeans exposed to low root temperature. *Plant Physiol.* **80**: 249-55.
- Waughman, G. J. 1977. The effect of temperature on nitrogenase activity. *J. Exp. Bot.* **28**: 949-60.



Welty, L. E.; Prestbye, L. S.; Hall, J. A.; Mathre, D. E. and Ditterline, R. L. 1988. Effect of fungicide seed treatment and rhizobia inoculation on chickpea production. *Applied Agric. Res.* **3**: 17-20.

Zhang, F. and Smith, D. L. 1994. Effect of low root zone temperatures on the early stage of symbiosis establishment between soyabean and *Bradyrhizobium japonicum*. *J. Exp. Bot.* **45**: 1467-73.

Zhang, F. and Smith, D.L. 1995. Pre-incubation of *Bradyrhizobium japonicum* with genistein accelerates nodule development of soybean at suboptimal root-zone temperature. *Plant Physiol.* **108**: 961-68.

Zhang, F. and Smith, D. L. 1997. Application of genistein to inocula and soil to overcome low spring soil temperature inhibited of soybean nodulation and nitrogen fixation. *Plant Soil.* **192**: 141-51.

## CHAPTER 5

# Physiology of Growth and Yield Components

The yield components of a grain crop can be expressed as:

$$Y = Nr. Ng. Wg$$

where  $Y$  = grain yield,  $Nr$  = number of reproductive units (e.g. heads, ears, panicles, pods, etc) per unit of ground area,  $Ng$  = number of grains per reproductive unit, and  $Wg$  = the average weight of the grain (1000 grain weight); also termed as test weight or grain size.

For any crop, there are two components of yield attributes, termed as high expression components and low expression components. For grain legume crop, in general, these attributes are listed below:

- A. High expression factors;** indicated relative to components under B
  - Weight per seed (test weight)
  - Seeds per pod
  - Pods per plant
  - Plants unit land area
- B. Low expression factors;** indicated relative to components under A:
  - Dry matter per plant, dry matter per unit land area, leaf area per plant, leaf area index, leaf area duration, etc.

The extent of association between yield and its components is of greater importance for getting higher yield in chickpea (Bhattacharya *et al.*, 1995; Basu and Singh, 2003). The major yield components of chickpea are total dry matter, number of primary and secondary branches per plant, pods per plant, seeds per pod, test weight, and harvest index (Singh and Bhattacharya, 1994; 1995; Kumar *et al.*, 2003). Number of pods is dependent on number of flowering nodes on primary, secondary and tertiary branches. Primary and secondary branches are the main contributors to yield (Summerfield and Wani, 1980; Chatterjee and Bhattacharya, 1986). Each flowering node in chickpea bears one pod (mono podal), but in some cultivars twin pods have also been reported (Athwal and Brar, 1964). It is suggested that double poded characteristic



in chickpea may confer a small but significant yield advantage under conditions in which it is well expressed. Phenology plays an important role in influencing these components and consequently in determining the yield (Sheldrake *et al.*, 1978).

Yield is a complex phenomenon, and is governed by a number of factors, viz. genotype, environment, and genotype  $\times$  environment interaction. Yield related physiological processes are associated with plant processes, e.g. photosynthetic efficiency, and partitioning of photoassimilates to economic yield. The potential yield of a crop can be realized when crops are grown under optimal condition, i.e. in an environment where they are suitably adapted, light, nutrient and moisture are not limiting, and diseases and pests and other abiotic and biotic stresses are effectively controlled.

Pulses are sensitive to photoperiod, temperature, as well as to their interaction effects. Beside these environmental factors agronomic practices plays significant role in realization of yield. Availability of water is a major constraint in realizing the yield potential. It is observed that irrigation at critical stage, as a life saving irrigation, is favourable for higher productivity in pulses (Ali *et al.*, 2004). Reduction in yield up to 17% is observed to be due to limited supply of irrigation water at critical growth stage in chickpea (Nanda and Saini, 1992). Water stress causes delayed flower initiation, reduction in shoot: root dry weight ratio and in yield components in chickpea. Early podding phase is reported to be the most sensitive stage to water deficit in fababean, resulting in reduction in harvest index and seed yield to the extent of 50% (Mwanamwenge *et al.*, 1999). In chickpea yield reductions calculated under induced drought conditions as compared to normal is suggested to provide a realistic estimate for screening varieties for drought condition (Begg and Turner, 1976; Turner *et al.*, 2001; 2005).

The productivity of chickpea is reported to be highly correlated with the maximal leaf area. In mungbean the maximum dry matter and grain yield are observed to be related positively to leaf area (Panwar *et al.*, 1986). Saxena (1984) reported that an increase leaf area index from 1.5-3.0 doubled the yield under irrigated condition at ICRISAT in chickpea. Number of pods per plant increased with increase in leaf area per plant; primarily because of large leaf area is generally associated with more nodes in chickpea (Saxena, 2003) and in mungbean (Panwar *et al.*, 1986). It is also observed that there is no further increase in pod number per plant once a decline trend in leaf area has started. Partial defoliation or 15% reduction in light intensity by shading reduced grain yield significantly in chickpea (Saxena and Sheldrake, 1980a; 1980b; Johenson *et al.*, 1990), and in mungbean (Nanda and Saini, 1987).

Positive associations between seed yield with biological yield as well as with harvest index in chickpea have also been reported by others (Lal, 1976; Bahl and Jain, 1977; Sinha 1997). However, productivity of pulses



in general is low because of low biomass production, for instance; the biomass production in chickpea and lentil hardly exceeds 8-10 tonnes/ha. *Vigna* species, including mungbean, urd bean, cowpea, and moth bean, when sown in *kharif* produce 4-5 tonnes/ha. When these are sown in summer dry matter production is only 3 tonnes/ha, but exceeds 14 tonnes/ha when crops are grown in *rabi*. While comparing biomass production, grain yield and harvest index of chickpea, 257 RILs along with their parents were sown at three locations in India, viz. ICRISAT, Guntur, and Kanpur, and it was observed that these attribute were poorly expressed in the Northern part (Kanpur) as compared to the Southern part (ICRISAT and Guntur) of the country (Krishnamoorthy *et al.* 2004). Poor association between biomass production, grain yield and harvest index was attributed due to inefficient partitioning of biomass to economic yield on account of terminal drought experienced by the crop at Kanpur.

In mungbean Saini and Das (1979) indicated that high yield in summer crop was associated with high NAR (net assimilation rate). Values for total biomass production and leaf area index indicated that mungbean was more efficient per unit leaf area in summer than in rainy season. Mungbean leaves are thicker in summer as indicated by their higher specific leaf area (SLA). Genotypic differences with respect to NAR are not significant. However, the NAR declines as the season progresses and the leaf area index increases (Patel *et al.*, 1992). Kuo *et al.* (1980) concluded that yield may be enhanced by selection for high specific leaf weight (SLW), high LAI, and high RuBISCO activity. Significant genotypic differences were obtained for each of these characters in mungbean.

Nuhawan and Chandra (1980) reported positive association between yield and LAI, NAR, LAD (leaf area duration) and RLGR (relative leaf growth rate) during one or more growth phases, but could not get a consistent relationship in mungbean. Thandapani (1985) found that parameters such as leaf area and LAI at peak vegetative or peak flowering phases, and SLW at peak flowering stage, are associated positively with high yield in mungbean. Srinivasan *et al.* (1985) observed significant genotypic differences with respect to their photosynthetic rate at different growth stages, pod yield and harvest index in mungbean. Panwar *et al.* (1986) reported high yielding variety of mungbean possess larger leaf area. Panwar and Thakur (1997) reported that during summer a longer duration variety of mungbean yield higher than the shorter duration variety, particularly when VAM (*vesicular arbuscular mycorrhizal*) is applied in addition to *Rhizobium* treatment under irrigated condition.

### YIELD DETERMINING COMPONENTS

A useful conceptual frame work for analyzing yield (Y) variation in grain legumes is provided by the relationship as given below:



$$Y = TDM \times HI$$

where, TDM is total dry matter, and HI is harvest index.

Various models have been proposed and these models have significant impact on grain yield. Some such models are given below:

- $Y = C \times Dr \times p$  (Duncan *et al.*, 1978)
- $Y = RI \times RUE \times HI$  (Monotesta, 1977)
- $Y = T \times TE \times HI$  (Passioura, 1977)
- $Y = T \times TE \times HI$  (Fischer, 1981)

where, Y is crop yield, C is crop growth rate, Dr is the duration of reproductive growth, p is proportion of C partitioned to yield, RI is the radiation interception, RUE is radiation conservation efficiency into dry matter production, HI is harvest index, T is transpiration rate, and TE is transpiration efficiency.

Genotypic variations in TE and its correlation with carbon isotopic discrimination ( $\Delta^{13}C$ ) has been determined in chickpea (Udayakumar *et al.*, 1996) and in cowpea (Ismail and Hall, 1992; Ismail *et al.*, 1994), where it is observed that TE is negatively correlated with discrimination of  $^{12}C$  (White, 1993). The encouraging results to date suggest that determination of  $\Delta^{13}C$  could be useful and inexpensive technique for screening and identification of genotypes with high TE, especially during early generation selection when lower levels of precisions are acceptable (Turner *et al.*, 2001).

The HI, as an aspect of physiological approach to enhance economic yield has drawn larger attention (Jain, 1975; Pawar and Bhatia, 1980; Kuo *et al.*, 1980; Malik *et al.*, 1986). Enhancement in yield is plausible by high net accumulation of photosynthates along with its efficient partitioning towards seed growth. HI may be used as a very useful parameter in breeding programme. A schematic relationship among various environmental, morphological and physiological processes in regulating yield and yield attributes are given in Fig. 1.





- Chatterjee, B. N. and Bhattacharya, K. K. 1986. *Principles and Practices of Grain Legume Production*. Oxford & IBH Pub. Co. Pvt. Ltd., New Delhi.
- Duncan, W. G.; Mc Cloud, D. E.; Mc Graw, R. L. and Boote, K. L. 1978. Physiological aspects of peanut yield improvement. *Crop Sci.* **18**: 1015-20.
- Fischer, R. A. 1981. Optimising the use of water and nitrogen through breeding of crops. *Plant Soil.* **58**: 249-78.
- Ismail, A. M. and Hall, A. E. 1992. Correlation between water use efficiency and carbon isotope discrimination in diverse cowpea genotypes and isogenic lines. *Crop Sci.* **32**: 7-12.
- Ismail, A.M.; Hall A. E. and Bray, E. A. 1994. Drought and pot size effects on transpiration efficiency and carbon isotope discrimination of cowpea accessions and hybrids. *Australian J. Plant Physiol.* **21**: 23-25.
- Jain, H. K. 1975. Development of high yielding varieties of pulses: prespective, possibilities and experimental approaches. In: *Proceeding of International Workshop on Grain Legume*, ICRISAT, Patencheru India, pp. 177-85.
- Johnson, D. A.; Assay. K. H. A.; Tieszen, L. L.; Ehleringer, J. R. and Jafferson, P. G. 1990. Carbon isotope discrimination: Potential in screening cool season grasses for water limited environments. *Crop Sci.* **30 L**: 338-43.
- Kuo, C. G.; Hsu, F. H.; Tsay, J. S. and Chaudhary, A. H. 1980. Variation in specific leaf weight and RuDPCase activity in mungbean. *J. Plant Sci.* **60**: 1059-62.
- Krishnamoorthy, L.; Kashiwagi, J.; Panwar, J. D. S.; Roco, Y. K. and Serraj, R. 2004. Multi location analysis of yield components of chickpea RIL population grown under terminal drought. *Indian J. Pulses Res.* **17**: 17-24.
- Kumar, N.; Nandwal, A. S.; Luthra, V. S.; Dahiya, B. S.; Sheoron, I. S.; Waldia, R. S. and Panwar, J. D. S. 2003. Studies on dry matter partitioning and yield variations in different genotypes of chickpea. *Indian J. Plant Physiol.* (**Special Issue**): 91-97.
- Kuo, G. C.; Jung, M. C. H. and Tsou, S. C. S. 1980. Translocation of  $^{14}\text{C}$  urea as a source of photosynthate in mungbean during reproductive period. *Hort. Sci.* **13**: 580-81
- Lal, S. S.: Yadav, C. P. and Chandra, S. 1976. Suppression of pod fly damage through varietal selection. *International Pigeonpea News letter.* **5**: 42-43.
- Malik B. A.; Tahir, M.; Hussain, S. A. and Chaudhary, A. H. 1986. Identification of physiologically efficient genotypes in mungbean. *Pakistan J. Agri. Research.* **7**: 41-43.
- Monotesta, J. L. 1977. Climate and efficiency of crop production in Britain. *Phylosophy and Trans Royal Soc. London.* **Series B.** **281**: 277-94.
- Mwanamwenge, J.: Loss, S. P.; Siddique, K. H. M. and Cocks, P. S. 1999. Growth, seed yield and water use of faba beans in a short season Mediterreaneon type environment. *Aust. J., Exp. Agric.* **38**: 171-80.

- Nanda, R. and Saini, A. D. 1987. Effect of temperature, day length and humidity on the leaf appearance in green gram. *Indian J. Agric Sci.* **57**: 645-50.
- Nanda, R. and Saini, A. D. 1992. Effect of restricted soil moisture on yield and yield attributes in chickpea (*Cicer arietinum* L.). *Indian J. Plant Physiol.* **35**: 16-24.
- Nuhawan, D. C. and Chandra, S. 1980. The physiology of plant growth with particular reference to the concept of photosynthetic efficiency in mungbean. *Indian J. Plant Physiol.* **23**: 40-46.
- Patel, D. B.; Purohit, K. R. and Shah, R. R. 1992. Physiological analysis of yield variation in mungbean (*Vigna radiata* [Roxb.] Wilczek). *J. Agron. Crop Sci.* **168**: 128-32.
- Panwar, J. D. S. and Thakur, A. K. 1997. Mycorrhizae: Biofertilizers for the future. *Proceedings of Third National Conference on Mycorrhiza*, Organized by Tata Energy Research Institute (TERI) at CCHAU, Hisar, pp. 471-77.
- Panwar, J. D. S.; Shukla, D. S. and Sirohi, G. S. 1986. Growth and developmental aspects in relation to yield of mungbean (*Vigna radiata* L. Wilczek.). *Indian J. Plant Physiol.* **29**: 312-16.
- Passioura, J. 1977. Drought environment: Physiological, biological and agricultural perspectives. *J. Exp. Bot.* **58**: 113-17.
- Pawar, S. E. and Bhatia, C. R. 1980. The basis for grain yield differences in mungbean cultivars and identification of yield limiting factors. *Theoretical Appl. Gene.* **57**: 171-75.
- Saini, A. D. and Das, K. 1979. Studies on growth and yield of three mungbean cultivars. *Indian J. Plant Physiol.* **22**: 147-55.
- Saxena, N. P. 2003. Management of drought in chickpea, a holistic approach. In: *Management of Agricultural Drought-Agronomic and Genetic Options*. Saxena N. P., (Ed.). Oxford & IBH Pub., New Delhi, India, pp. 103-22.
- Saxena, N. P. 1984. The physiology of tropical field crops. Goldsworthy P. R. and Fisher N. M., (Eds). Wiley, New York, pp. 419-52.
- Saxena, N. P. and Sheldrake, A. P. 1980a. Physiology of growth, development and yield of chickpea in India. *Proceedings of International Conference on Chickpea Improvement*, 28 Feb-2 March, 1979, Patancheru, India, pp 106-20.
- Sheldrake, A. R.; Saxena N. P.; and Krishnamurthy, L. 1978. The expression and influence of the "double-podded" character in chickpea (*Cicer arietinum* L.). *Field Crops Res.* **1**: 243-53.
- Singh, D. N. and Bhattacharya, A. 1994. Consolidated report of rabi pulses 1993-94 of All India Coordinated Pulse Improvement Programme. Presented at Rajasthan Agricultural University, Bikaner, India.
- Singh, D. N. and Bhattacharya, A. 1995. Consolidated report of rabi pulses 1994-95 presented at AICRP on chickpea.



Sinha, S. K. 1997. Food legumes: Distribution, adaptability and biology of yield. *In: FAO Plant Production and Protection*, paper 3, FAO, Rome, Italy, pp. 1-102.

Srinivasan, P. S.; Chandrababu, R.; Natarajratnam, N. A. and Rangaswamy, S. R. 1985. Leaf photosynthesis and yield potential in greengram cultivars. *Tropical Agric.* **62**: 222-24

Summerfield, R. J. and Wani, H. C. 1980. *In: Advances in legume Science*. Summerfield R. J. and Bunting A. H., (Eds). London H M S O, pp. 17-36.

Thandapani, V. 1985. Leaf growth attributes as comparative physiological factors for the genotype of green gram in relation to yield. *Madras Agric. J.* **72**: 126-32.

Turner N. C.; Danies, S. L.; Plumner J. A. and Siddique, K. H. M. 2005. Seed filling in grain legumes under water deficits with emphasis on chickpea. *Adv. Agric.* **87**: 212-50.

Turner, N. C.; Wright, G. C. and Siddique, K.H.M. 2001. Adaptation to grain legumes (Pulses) to water limited environment. *Adv. Agron.* **71**: 193-231.

Udayakumar, M.; Wright, G. C.; Prasad, T. G. and Rao, R. C. N. 1996. Variation for water use efficiency in grain legumes. *Second International Crop Science Congress*. 17-24 Nov., 1996, New Delhi, India.

White, J. W. 1993. Implication of carbon isotope discrimination studies in breeding common bean under water deficits. In: Stable isotopes and plant carbon water relationship. Shlernger J.R., Farquhar G.D. and Hall A.E., (Eds). Academic Press, San Diego, C. A, pp. 387-98. ●

## **CHAPTER 6**

# **Water, Light and Radiation-Use Efficiency**

**I**n agronomic terms, water-use efficiency (WUE) is defined as the yield of the marketable crop produced per unit of water used in evapotranspiration (ET). In the literature several related terms are used to define water-use efficiency. Crop physiologists takes into account the biomass produced per ml of water transpired (T), and call it as transpiration efficiency of biomass production (TE), and the crop yield (Y) is expressed by the equation as given below:

$$Y = ET \times T \times T/ET \times TE \times HI$$

Above equation describes that grain yield is a function of the amount of water used by the crop (evapotranspiration ET), the proportion of that water actually transpired by the crop (T/ET), the transpiration efficiency (TE), and the effectivity by which biomass is partitioned into harvested product, i.e. the ratio between grain yield to biomass; termed as harvest index (HI) (Condon *et al.*, 2004). None of the components of above yield frame work is independent of the other; however, each may be considered for genetic improvement to improve the yield. At leaf-level water-use efficiency, also term 'Intrinsic water-use efficiency' ( $W_T$ ), is defined as the ratio between instantaneous rates of  $CO_2$  assimilation (A) to the rate of transpiration (T), directly relates to TE. The instantaneous rates of both A and T can be described by a relatively simple equation (Condon *et al.*, 2002) as given below:

$$A = gc (C_a - C_i)$$

and

$$T = gw (W_i - W_a)$$

where, gc is stomatal conductance to  $CO_2$ , gw is stomatal conductance to water vapour,  $(C_a - C_i)$  and  $(W_i - W_a)$  are concentration gradients of  $CO_2$  (C), and water vapour (W) between air out side leaf (<sub>a</sub>) and inside the leaf (<sub>i</sub>).



The intrinsic water-use efficiency ( $W_T$ ) is the ratio of  $A$  and  $T$ , and expressed as:

$$W_T \approx 0.6 c_a (1 - C_i / C_a) / (W_i - W_a)$$

Equation (3) signifies that  $W_T$  is a negative function of the ratio of  $C_i$  (inter cellular  $CO_2$  concentration) and  $C_a$  (atmospheric  $CO_2$  concentration).

For  $C_3$  plants growing under normal (unstressed) condition, the  $C_i / C_a$  is typically 0.7 (Farquhar *et al.*, 1989). This operating value of  $C_i / C_a$  is determined by a balance between stomatal conductance and photosynthetic capacity. Stomatal conductance influences the supply of  $CO_2$  to leaf interior, whereas photosynthetic capacity takes into account the demand of  $CO_2$  for the process of photosynthesis at the site of carboxylation in the chloroplasts. The photosynthetic capacity may also be explained as the amount of activity of photosynthetic machinery per unit of leaf area, i.e. the photosynthetic rate. A lower value of  $C_i / C_a$ , i.e. improved  $W_T$  can be achieved through lower stomatal conductance to  $CO_2$  or by higher photosynthetic rate, or by the combination of both.

In general the water-use efficiency of pulses is much higher than any of the cereals. Among all grain legumes the water-use efficiency of lentil is much higher than any legume such as broad bean and soybean (about 2 kg/m), (Katerji *et al.*, 2001). Guar genotypes with medium maturing duration generally exhibit relatively higher irrigation water-use efficiency (16.3-19.2) than the early and late maturing genotypes (Stafford, 2008).

In fact, water is becoming a costlier input in agriculture. There is a need to select crops and their genotypes with high water-use efficiency. One of the breeding approaches under rainfed condition is to develop genotypes with improved water-use efficiency. There is no easy way to quantify water-use efficiency of crop plants.

Atmospheric  $CO_2$  contains approximately 1.1%  $^{13}C$  and 98.9%  $^{12}C$ . During photosynthesis, plants discriminate against  $^{13}C$  because of small differences in the chemical and physical properties imparted by the differences in mass. This discrimination is used to identify plants of various photosynthetic groups (Udayakumar and Prasad, 1993). Analysis of  $^{13}C$  discrimination ( $\Delta$ ) during photosynthesis is a reflection of  $CO_2$  and  $H_2O$  diffusive processes and carboxylation reaction, and hence could be used to assess differences in water-use efficiency (Udayakumar and Prasad, 1993). Many workers, including Farquhar and Richards (1984), have indicated that carbon isotopic discrimination ( $\Delta^{13}C$ ) technique may be used effectively to quantify water-use efficiency ( $W_T$ ) in many  $C_3$  species, and observed a negative association between carbon isotopic discrimination ( $\Delta^{13}C$ ) and  $W_T$ . In pulses, such negative correlations have been reported in peanut (*Arachis* sp.) (Hubic *et al.*, 1986), cowpea (*Vigna unguiculata* L.) (Ismail and Hall, 1992), chickpea (*Cicer arietinum* L.) (Udayakumar *et*

*al.*, 1996) and in common bean. However, Condon *et al.* (1987) observed a positive correlation between carbon isotope discrimination with grain yield and dry matter production in field grown wheat, and Krishnamurthy *et al.* (2007) reported poor regression coefficient between  $\Delta^{13}\text{C}$  and transpiration efficiency (TE) in groundnut RIL population under stress.

The  $\Delta^{13}\text{C}$  values obtained using leaves or whole plant provides similar results. Therefore, any of these plant parts can be used for the identification of  $W_T$  efficient genotypes of  $C_3$  plant species as listed above; nevertheless, further studies are required on other  $C_3$  plants for usefulness of this technique.

If facilities are available, determination of  $\Delta^{13}\text{C}$  values are convenient and reliable for screening therefore, this technique has been reported as an useful indicator for identification of genotypes differing in  $W_T$  (Condon *et al.*, 2002; Turner *et al.*, 2001). A strong association has been reported between specific leaf area (SLA) and  $\Delta^{13}\text{C}$  as well as TE and a low genotype by environment interaction for the relationship between SLA and TE. These led Wright *et al.* (1994) to suggest SLA as an economical surrogate tool to select for TE.

However, relationship between crop yield and water-use efficiency (measured on the basis of carbon isotopic discrimination technique) has been reported to be highly variable. The major reasons for variations in water-use efficiency in various genotypes, as proposed by Condon *et al.* (2002) and Vijaylaxmi *et al.* (2005), has been due to:

- Variation in crop growth rate,
- Rate of water-use by crop, and
- Interaction of growth and water-use over the crop duration to produce seed yield.

In annual crops there is considerable scope for improving water-use efficiency. However, the scope of increasing seasonal water-use efficiency is limited. Timely sowing, early crop vigour, use of nitrogenous fertilizers, and high planting densities have been suggested for enhancing water-use efficiency (Richards *et al.*, 2002), but in fact in all such situations though there has been an increase in yield, but not in water-use. Bolger and Turner (1999) reported higher rainfall use efficiency in wheat and lupine and also yield and water-use efficiency in pasture, but with little effect on water-use.

### RADIATION/LIGHT-USE EFFICIENCY

Radiation use efficiency (RUE,) takes into account the plant dry matter produced per unit of radiation intercepted (g/MJ) (Monteith, 1977). Nearly 45% of the incoming solar radiation is in the visible region of the spectrum and green plants are able to photosynthesize in this spectrum range (400-700 nm), therefore, it is proposed that instead of radiation use efficiency, term light use efficiency be used. Light use



efficiency is defined as the ratio of net photosynthesis to absorbed photosynthetically active radiation (APAR). Major factor which determines light utilization efficiency by a crop is the amount of photosynthetically active radiation (PAR) absorbed by the crop canopy. Light absorption by the crop canopy follows Lambert-Beers law, which is expressed as given below:

$$I_i/I_0 = e^{-kL} \dots\dots\dots(4)$$

where,  $I_0$  is PAR above canopy,  $I_i$  is PAR below the  $i^{\text{th}}$  layer of leaves,  $L$  is LAI of  $i^{\text{th}}$  layer of leaves,  $k$  is extension coefficient (it is a characteristic of the canopy and takes into account the pattern of leaf display or arrangement in the canopy), and 'e' is the base of natural log. In equation (4),  $I_i/I_0$  is also termed as transmittance (T).

The equation (4) indicates that when light enters in crop canopy the rate of decrease in radiation power with the amount of leaf area present in that layer of the canopy or as the leaf area index increases in arithmetic proportion the amount of transmitted light decreases in logarithmic proportion.

Depending upon crop and its genotype, crop growth stage, agronomic practices and environmental conditions, leaf area development in crop plants varies, and it critically determines the radiation use efficiency (RUE). Canopy structure, though genetically controlled but strongly regulated by the cultural practices and environmental conditions, significantly influences the light utilization efficiency in crop plants.

Radiation use efficiency is found to vary widely, even in a given species (Jeuffroy and Ney, 1997). Different values for RUE have been reported, viz. for pea it is estimated to vary between 0.96 to 1.46 g aerial dry matter/MJ by Heath and Hebblethwaite (1995), 1.25 g DM/MJ by Pyke and Hedley (1985), 2.36 g DM/MJ by Wilson *et al.* (1985) and 1.43 g DM/MJ by Martin *et al.* (1994) under drought condition,. For pigeonpea values for  $k$  are reported to be 0.9 g DM/MJ by Natrajan and Willey (1980a; b), 1.23 g DM/MJ by Hughes and Keatinge (1983), 1.30 g DM/MJ by Muchow (1985) and 1.62 g DM/MJ by Thirathan *et al.* (1987). However, Charles-Edwards (1982) suggested that if senescent leaves are to be considered, then RUE value may be as large as 2.2g/MJ.

In any crop with increase in LAI there is increase in RUE, as it increases the light interception by leaves. The RUE is the minimum after germination, which increases gradually with increase in LAI and reaches the maximum when crop attains optimum LAI. As LAI increases further, i.e. above optimal LAI, the leaves present in the lower strata of the crop canopy survive at light intensity below 'light compensation point', and such leaves depend upon upper leaves for their carbon nutrition; therefore, instead of contributing to the growth of plant they drain assimilates synthesized by upper leaves. Hence, increase in LAI, above optimal LAI, results in gradual reduction in RUE by the crop.



Most of the pulses exhibit indeterminate growth habit. Once flowering has been initiated, there is further increase in leaf area and flowering also continues. In such situations reproductive growth does not coincide with optimum LAI development and, therefore, in pulses with indeterminate growth, RUE is not as efficient as observed in crops with determinate growth habit such as in wheat and barley, etc. Under rainfed condition leaf area development is much lower than that attained under irrigated condition; it is also one of the reasons that under rainfed condition RUE is much lower than that under irrigated condition.

Depending upon genotype and agro-ecological conditions, leaf area index (LAI) in chickpea ranges between 2 and 4. The LAI under rainfed condition is much lower than that under irrigated condition; therefore, under moisture limiting condition light interception is not up to the fullest extent, resulting in reduced RUE. Once flowering has initiated further flowering and pod formation in most of the chickpea genotypes goes on simultaneously throughout the crop period of about 120-130 days. Therefore, reproductive phase light interception is not to its fullest extent. Again, the LAI and light interception varies from one genotype to another (Aggrawal *et al.*, 1984).

In pigeonpea initial phase of growth is slow. Much variation is observed in growth pattern and leaf area development in early, medium and late maturity types of pigeonpea. In late maturing genotypes LAI and crop growth rate (CGR) increase exponentially from 70 days after sowing (DAS), indicating that light utilization efficiency is poor before 70 DAS, but increases afterwards. Although in late maturing pigeonpea genotypes the maximum light interception takes place at LAI 6-7, but the crop may attain LAI 13.4-15.5 at about 140 DAS (Hughes *et al.*, 1981). It implies that at LAI above 6-7 in long duration pigeonpea, most of the leaves in the lower strata of the canopy are although transpiring but surviving below light compensation point, and there is intraplant competition for assimilates resulting in reduced dry matter production and decreased RUE. Extra-short, short, and medium-duration pigeonpea genotypes may attain LAI up to 3, 4 and 6, respectively (Robertson *et al.*, 2001), and it may not be sufficient for maximization of incident light interception, resulting in reduced RUE.

In moth bean, in some of the genotypes, excessive leaf area development during reproductive growth phase may lead to reduction in photosynthetic efficiency due to shading of leaves present in the lower strata of the crop canopy, and therewith reducing the RUE of the crop (Srivastava and Soni, 1995).

### NUTRIENT-USE EFFICIENCY

In agriculture, nutrient use efficiency (NUE) may be defined as economic yield per unit of input, i.e. fertilizers applied. In scientific



literature, the NUE is generally defined as dry matter or fresh weight produced per unit content of nutrient. On the basis of this definition an efficient crop variety has the potential to absorb large amount of nutrients and convert them into plant production on highly enriched soil, where as less efficient variety reaches a yield plateau. However, in scientific review 18 different forms of nutrient use efficiency has been used. Four of them, as listed below, are very commonly used (Bruulsema, 2010):

***Partial factor productivity:*** It takes into account crop yield per unit of nutrient applied, and explains the productiveness of the crop in relation to the applied nutrient.

***Agronomic efficiency:*** It takes into account the yield increase per unit of nutrient applied, and takes into account that the improvement in productivity was gained by the use of that nutrient.

***Partial nutrient budget:*** It indicates the amount of nutrient in harvested crop per unit of nutrient applied, and explains the amount of nutrient is taken out of the system in relation to the amount added.

***Recovery efficiency:*** It indicates increase in above-ground crop uptake per unit of nutrient applied, and explains the amount of the nutrient taken up by plants out of the applied amount.

Plant growth is a complex process and regulated by a number of factors. As far as mineral nutrients are concerned, at least 15 elements are traced out as essential for normal growth and development of plants, and deficiency of any of the elements may influence the nutrient-use efficiency in plants. It has been the major reason that in the initial phases of green revolution fertilizer-use efficiency was around 12 (i.e. 12 kg of grain production per kg of fertilizer applied), but now has come down to nearly 8, and added doses of N, P, and K instead of increasing fertilizer-use efficiency are registering a decreasing trend. Now, besides N, P, K, levels in soil, elements like S, Zn, Fe, etc. have also declined below the critical level and, therefore, limiting the crop yield and nutrient use efficiency. It implies that use of 'balanced fertilizer' is one of the major factors to determine the fertilizer-use efficiency in crop plants. Now the major concern is not only to improve fertilizer-use efficiency of crops, but also to consider the sustainability of the system, i.e. in terms of increasing yield and diminishing nutrient losses without adversely affecting the agro-ecosystem.

Pulses have ability to fix atmospheric nitrogen; therefore, their nitrogen requirement is low. The ability and efficiency to fix atmospheric nitrogen can be further increased by seed treatment with specific strain of *Rhizobium*. Such treatment has been proved to increase crop yield by 10-20%. Since development of effective nodules takes some time after sowing, and during this period for vegetative development of crop nitrogen is required, hence a basal dose of nitrogenous fertilizers have



been reported to enhance crop vigour and nitrogen fixation ability, e. g. 10-15 kg/ha in pigeon pea, 12.5 kg/ha N in mung bean, 12.5 kg/ha in moth bean and urd bean, 12-24 kg/ha in guar, is recommended. Nitrogenous fertilizer requirement for rajmash is high, and is around 100-120 kg/ha. Nevertheless, higher doses of nitrogenous fertilizer suppress nodulation, promote excessive vegetative growth, and reduce yield as well as nutrient use efficiency. However, foliar application of 2% urea at 30 and 45 days after sowing is reported to increase grain yield in urd bean and mungbean (<http://www.tnau.ac.in/tech/ricetips.pdf>)

As compared to cereals, phosphorus and potassium requirements of pulses are also less, but they respond to applied P, and to some extent to K application. To supplement phosphorus requirements of pulses, in pigeon pea 17- 20 kg/ha, in mungbean 40 kg/ha, in rajmash 60 kg/ha, in moth bean 25 kg/ha, in guar 60-74 kg  $P_2O_5$ /ha are recommended as basal doses. In moth bean 25 kg  $K_2O$ /ha and in guar 60-74 kg  $K_2O$ /ha are recommended as basal doses for optimal productivity and enhanced fertilizer use efficiency. The recommended doses vary with respect to crop and the agro-ecological condition. However, to increase their use efficiency, it is recommended that these may be placed in the soil below the seeds.

In areas where deficiencies of other essential mineral elements prevail, it is essential to correct them in time to enhance fertilizer use efficiency. In areas where there is deficiency of sulphur, there agricultural grade gypsum or phosphogypsum is recommended in such areas. Depending upon crop and soil properties, it is recommended that gypsum @ 100-200 kg/ha, be applied before sowing and mixed with the soil (National Food Security Mission).

As compared to other crops, calcium requirement of pulses is more, and it limits crop productivity in acidic soils. It is recommended that in acidic soils, in order to enhance fertilizer use efficiency in pulses, lime, dolomite, paper mill sludge or basic slag can be applied in soil before sowing. Application of powders of these compounds @ 2-4 q/ha in furrows has been prescribed (National Food Security Mission).

Pulses also require supplementation of zinc for optimal productivity. Depending upon crop and the soil type, zinc sulphate (heptahydrate) @ 25-60 kg/ha, is recommended once in a year or after every 2 years. Foliar application of 500 L of 0.5% (w/v) aqueous solution of zinc sulphate/ha is also recommended. Foliar application of 0.5% ferrous sulphate is recommended to reduce iron chlorosis (Department of Crop Physiology, Tamil Nadu Agricultural University, Tamil Nadu). Deficiency of boron is observed in high rainfall areas, and to correct it borax @ 10 kg/ha as basal, or foliar spray of its 0.5% aqueous solution 15 days after sowing and at flowering stage are recommended (National Food Security Mission).

Pulses grown in north eastern and eastern states of the country show molybdenum deficiency, and in such salutations, it is recommended that



application of 2-4 kg/ha sodium molybdate or 2-3 kg/ha ammonium molybdate as a basal dose, or foliar application of 0.1-0.3% (w/v) aqueous solution of ammonium molybdate at an interval of 10 days for 2 -3 times during crop growth is essential to enhance productivity (National Food Security Mission).

Besides use of *Rhizobium* culture for seed inoculation, use of phosphorus solubilizing bacteria (PSB) and VAM has also shown promising effect in reducing fertilizer doses and improving nutrient use efficiency in pulses.

The observations, therefore, indicate that use of balanced fertilizers depending upon the crop and the nutritional status of the soil along with seed inoculation by suitable *Rhizobium* culture, and VAM in some cases, the nutrient use efficiency of pulses can be improved on sustainable basis.

Recent developments have indicated that significant food production is to be derived from nutrient-poor soils; therefore, as compared to an inefficient variety, the efficient variety must have the ability to produce more from a given amount of nutrient. The efficient genotypes may have efficient nutrient acquisition system, plasticity in growth rate to make it compatible with nutrient supply, and/or efficient internal economy, which may result from efficient distribution within plant and/or lower requirements at the functional sites. Therefore, the nutrient-use efficiency depends not only on the amount of nutrients available in the soil, but also its uptake, transport, storage and distribution within the plant. Variations with respect to crop and their genotypes, and their requirements of specific nutrient for optimal growth also plays significant role in determining nutrient use efficiency of specific crop and their genotypes. In maize it has been observed that efficient and inefficient inbred line absorb Mg with same rates, but translocation to shoot is more in the efficient line. In celery single recessive gene is reported to control translocation of magnesium and boron to shoot (Clark, 1976). In maize a positive correlation between efficient nitrogen utilization and nitrate reductase activity has been reported (Warner *et al.*, 1969). Though boron, once it is absorbed is not effectively redistributed within plant, but groundnut is an exception of this (Campbell *et al.*, 1975). Roles of ion transporters and channels are well known in ion uptake and partitioning in plants.

There is a need to screen different pulse crops and their genotypes for the identification of efficient crop and the genotype under different agroclimatic conditions. Ion uptake and transport is under genetic control. Genes responsible for some of the transporters and ionic channels are well studied in *Arabidopsis thaliana* and many crop plants. However, not much work has been done on such aspects in pulse. Utilizing modern biotechnological tools it is possible to develop efficient genotype, in terms of nutrient use, with high productivity.

## REFERENCES

- Bolger, T. P. and Turner, N. C. 1999. Water use efficiency and water use of Mediterranean annual pastures in South Australia. *Australian J. Agric. Res.* **50**: 1035-46.
- Bruulsema, T. 2010. Effective nutrient use efficiency improvement. IPNI. Plant Nutrition Today. Summer 2007, No. 1. @ PlantNutrition on twitter.
- Campbell, L. C.; Miller, M. H. and Loneragan, J. F. 1975. Translocation of boron to plant fruits. *Australian J. Plant Physiol.* **2**: 481-87.
- Charles-Edwards, D. A. 1982. *Physiological Determinants of Crop Growth*. Sydney: Academic Press.
- Clark, R. B. 1976. Plant efficiencies in the use of calcium, magnesium and molybdenum. *In: Plant Adaptation to Mineral Stress in Problem Soils*. Cornell Univ. Agric. Exp. Stn. Spec. Pub, pp. 420.
- Condon, A. G.; Richards, R. A. and Farquhar, G. D. 1987. Carbon isotope discrimination is positive correlation with grain yield and dry matter production in field-grown wheat. *Crop Sci.* **27**: 996-1001.
- Condon, A. G.; Richard, R. A.; Rebetzke, G. J. and Farquhar, G. D. 2002. Improving intrinsic water-use efficiency and crop yield. *Crop Sci.* **42**: 122-31.
- Condon, A. G.; Richards, R. A.; Rebetzke, G. J. and Farquhar, G. D. 2004. Breeding for high water-use efficiency. *J. Exp. Bot.* **55**: 2447-60.
- Department of Crop Physiology, Tamil Nadu Agricultural University, Tamil Nadu, India. Tips for getting better yield. <http://www.tnau.ac.in/tech/ricetips.pdf>
- Farquhar, G. D. and Richards, R. A. 1984. Isotopic composition of plant carbon correlates with water use efficiency of wheat genotypes. *Australian J. Plant Physiol.* **11**: 539-52.
- Farquhar, J. D.; Ehleringer, J. R. and Hubic, K. T. 1989. Carbon isotope discrimination and photosynthesis. *Ann. Rev. Plant Physiol.* **40**: 503-37.
- Heath, M. C. and Hebblethwaite, P. D. 1995. Solar radiation interception by leafless, semileafless and leafed peas (*Pisum sativum*) under contrasting field conditions. *Ann. Appl. Biol.* **107**: 309-18.
- Hubic, K. T.; Farquhar, G. D. and Shorter, R. 1986. Correlation between water use efficiency and carbon isotope discrimination in diverse peanut germplasm. *Australian J. Plant Physiol.* **13**: 803-16.
- Hughes, G. and Keatinge, J. D. 1983. Solar radiation interception, dry matter production and yield in pigeonpea (*Cajanus cajan* (L.) Millspaugh). *Field Crop Res.* **6**: 171-78.
- Hughes, G. G.; Keatinge, J. D. H. and Scott, S. P. 1981. Pigeonpea as a dry season crop in Trinidad, West Indies. II. Interception and utilization of solar radiation. *Trop. Agric. (Trinidad)*. **58**: 191-99.



- Ismail, A. M. and Hall, A. E. 1992. Correlation between water use efficiency and carbon isotope discrimination in diverse cowpea genotypes and isogenic lines. *Crop Sci.* **32**: 7-12.
- Jeuffory, Marie-Hélène and Ney, B. 1997. Crop physiology and productivity. *Field Crop Res.* **53**: 3-16.
- Katerji, N.; van Hoorn, J. W.; Hamdy, A.; Mastrorilli, M. Oweis, T. and Erskine, W. 2001. Response of two varieties of lentil to soil salinity. *Agric. Water Management* **47**: 179-90.
- Krishnamurthy, L.; Vadez, V.; Jotsna Devi, M.; Serraj, R.; Nigam, S. N.; Sheshshayee, M. S.; Chandra, S. and Aruna, R. 2007. Variation in transpiration efficiency and its related traits in a groundnut (*Arachis hypogaea* L.) mapping population. *Field Crop Res.* **103**: 189-97.
- Martin, I.; Tenorio, J. L. and Ayerbe, L. 1994. Yield, growth and water use of conventional and semi-leafless peas in semiarid environments. *Crop Sci.* **34**: 1576-83.
- Monteith, J. L. 1977. Climate and the efficiency of crop production in Britain. *Philos. Trans. R. Soc. London. Ser. B.* **281**:277-94.
- Muchow, R. C. 1985. Phenology, seed yield and water use of grain legumes grown under different soil water regimes in a semi arid tropical environment. *Field Crop Res.* **11**: 81-97.
- Natarajan, M. and Willey, R. W. 1980a. Sorghum-pigeonpea intercropping and the effect of population density. I. Growth and yield. *J. Agric. Sci., Cambridge* **95**: 51-58.
- Natarajan, M. and Willey, R. W. 1980b. Sorghum-pigeonpea intercropping and the effect of population density. II. Resource use. *J. Agric. Sci., Cambridge.* **95**: 59-65.
- National Food Security Mission. Department of Agriculture and Cooperation. Ministry of Agriculture. Government of India. Krishi Bhawan, New Delhi. Guidelines for use of micronutrients, soil ameliorates and integrated nutrient management practices in NFSM states. <http://nfsm.gov.in/Micronutrient.pdf>.
- Pyke, K. A. and Hedley, C. L. 1985. Growth and photosynthesis of different pea phenotypes. In: *The Pea Crop*. (P. D. Hebblethwaite, M. C. Heath and T. C. K. Dawkins, eds.). Butterworths, London, pp. 297-350.
- Richards, R. A.; Rebetzke, G. J.; Condon, A. G. and van Herwardden, A. F. 2002. Breeding opportunities for increasing the efficiency of water use and crop yield in temperate cereals. *Crop Sci.* **42**: 111-21.
- Robertson, M.J.; Slim, S.N.; Chauhan, Y.S. and Ranganathan, R. 2001. Predicting growth and development of pigeonpea: Biomass accumulation and partitioning. *Field Crop Res.* **70**: 89-100.
- Srivastava, J.P. and Soni, C.P. 1995. Physiological basis of yield in moth bean [*Vigna aconitifolia* (Jacq.) Marechal] under rainfed conditions. *J. Agron. Crop Sci.* **174**: 73:77.

- Stafford, R. E. and McMichael, B. L. 2008. Effect of water stress on yield components in guar. *J Agron. Crop Sci.* **166**: 63-68.
- Thirathon, A.; Byth, D. E.; Fischer, K. S. and Whiteman, P. C. 1987b. Relationship between leaf area, radiation interception and dry matter production after flowering in short season pigeonpea. *In: Food Legume Improvement for Asian Farming Systems*. Proceedings of an International Workshop, held in Khon Kaen, Thailand, 1-5 September, 1986. Willis E. S. and Byth Khon Kaen D. E., (Eds). Australian Centre for International Agricultural Research (ACIAR), Department of Agriculture, Thailand, Faculty of Agriculture, Khon Kaen University, Thailand. Proceedings No. 18, pp. 252-253.
- Turner, N. C. 1999. Drought resistance: A comparison of two frame work. *In: Management of Agriculture Drought; Agronomy and Genetic Option*. (Saxena et. al., Eds)). Oxford and IBH Publishing Co. New delhi, pp. 545-557.
- Turner, N. C. 2001. Optimising water use. *In: Crop Science: Progress and Prospects*. Nosberger J., Geiger H. H., Struik P. C., (Eds). CAB International, *Crop Sci*: pp. 119-35.
- Udayakumar, M. and Prasad, T. G. 1993.  $^{13}\text{C}$  isotope discrimination in plants-a potential technique to determine water-use efficiency. *In: Selection for Water-use Efficiency in Grain Legumes*. Workshop held at ICRISAT Centre, Andhra Pradesh, India, 5-7 May 1993. (G. C. Wright and R. C. Nageshwara Rao, eds.), pp. 42-45.
- Udayakumar, M.; Wright, G. C.; Prasad, T. G. and Rao, R. C. N. 1996. Variation for water use efficiency in grain legumes. *In: Second International Crop Science Congress*, 17-24 November 1996, New Delhi.
- Vijaylaxmi, L.; Bhattacharya, A. and Panwar, J. D. S. 2005. Abiotic stress and different techniques. *In: Advances in Plant Physiology –A Treatise*. Hemantaranjan A., (Ed.). Scientific Publishers.
- Warner, R. L.; Hageman, R. H.; Dudley, J. W. and Lambert, R. J. 1969. Inheritance of nitrate reductase activity in *Zea mays* L. *Proc. Nat. Acad. Sci USA*. **62**: 758-92.
- Wilson, D. R.; Jamieson, P. D.; Jermyn, W. A. and Hanson, R. 1985. Models of growth and water use of field peas (*Pisum sativum* L.). *In: The Pea Crop*. Hebblethwaite P. D., Heath M. C. and Dawkins T. C. K., (Eds). Butterworths, London, pp. 139-55.
- Wright, R. C.; Nageswara Rao and Farquhar, G. D. 1994. Water-use efficiency and carbon isotope discrimination in peanut under water deficit conditions. *Crop Sci.* **34**: 92-97.



## **CHAPTER 7**

# **Physiological Aspects of Pulse-Cereal Intercropping**

**T**he characteristics of component crops, which are to be considered during intercropping are: (a) root system, (b) crop morphology, viz. height, branching pattern, canopy cover, (c) crop duration, viz. early, medium, late, very late as in pigeonpea, (d) row direction, (e) nitrogen economy, (f) phosphorus use efficiency, (g) weed control, and (h) diseases and insect control. Intercropping of pulses with cereals, pulses with pulses, and incorporation of pulses in the cropping system is known for its nitrogen economy and stable return, and as a more risk covering system.

### **NITROGEN ECONOMY**

Pulses are known to have the beneficial effect in improving the soil fertility, and generally leave behind considerable amount of nitrogen for use by the succeeding crops. Depending upon the pulse crop grown as preceding crop, it is estimated that pulses save 15-60 kg N/ha. Amount of nitrogen fixed by different pulse crops and nitrogen economy when different pulse crops are incorporated in cropping system (Table 1).

**Table 1.** Nitrogen economy when different pulse crops are incorporated in cropping system and the amount of nitrogen fixed by different pulse crops.

Cropping	Nitrogen economy (kg/ha)	Crop	Nitrogen fixed (kg/ha)
Pigeonpea-wheat	20	Source: Saraf (1981)	
Greengram-wheat	40		
Blackgram-wheat	40	Black gram-cotton	53 kg
Cowpea (grain)-wheat	20	Green gram-cotton	53 kg
Cowpea (fodder)-wheat	60	Cowpea-cotton	58 kg
Chickpea-maize	60		
Lentil-maize	20		
Pea-maize	10		
Lathyrus-maize	40		
Cowpea-maize	40	N fixed by legumes	N fixed (kg/ha)
Pigeonpea-maize	60-70	Cluster bean	37-196
Pigeonpea-pearl millet	40	Black gram	119-140
Pigeonpea-wheat	40	Ground nut	22-92
Pigeonpea-maize	20-49	Soybean	17-124
Pigeonpea-pearlmillet	30	Pigeonpea	10-88
Lentil-pearlmillet	40	Cowpea	73-240
Lentil-maize	18-30	Chickpea	17-85
Peas-pearlmillet	40	Lentil	35-77
Peas-maize	20-32	Green gram	55-66
Green gram-pearlmillet	30	Source: Venkateswarulu (2004)	
Lathyrus-maize	36-48		
Cowpea-pearlmillet	60		
Source: Lee and Wani (1989), Subbarao (1988)			

Nitrogen economy by pulse crops varies in different agroclimatic condition. Such variations are listed in Table 2.



**Table 2.** Nitrogen economy in pulse-based cropping system in different agro-climatic zones of India.

Agro-climatic zone	States represented	Representative soil	Location of experiment	Cropping system	Nitrogen economy (kg/ha)	Reference
V	Uttar Pradesh	Brown hill, alluvial, mountain	Faizabad	Mungbean-wheat	30	Yadav (1990) Singh and Verma (1985)
				Pigeonpea-wheat	12	
				Mungbean-wheat	37	
				Urd bean-wheat	41	
			Kanpur	Fodder-cowpea-wheat	43	Ali (1992), Baghel (2005)
				Cowpea (*F)-rice	44	
				Green gram-rice	35	
VI	Uttar Pradesh, Punjab, Rajasthan, Haryana	Red yellow deltaic, alluvial red loamy	Faizabad	Cow pea (*F)-wheat	40	Ali (1992), Baghel (2005)
			Ludhiana	Urdbean-wheat	30	
			Ludhiana	Cowpea-wheat	40	
			Ludhiana	Pigeonpea-wheat	30	
			Delhi	Fodder-cowpea-barley	40	
			Delhi	Sorghum + cow pea-wheat	75	
VII	Odisha, Bihar, West Bengal	Alluvial	Ranchi	Maize + urd bean or maize-soybean (Intercrop)	70	Ashok Kumar & Balyan (2002) Shivay <i>et al.</i> (2001)
VIII	Madhya Pradesh, Rajasthan, Uttar Pradesh	i) Alluvial, red, brown hill ii) Loamy sand	M.P., Jhansi Jobner	Chickpea-rice	30	Srivastava and Srivastava (1993)
				Lentil-rice		
				Pea-rice		
IX	Maharashtra, Madhya Pradesh	Alluvial, calcareous, desert	Maharashtra	a) Urdbean-wheat	30	Singh and Bajpai (1993) Sinsinwar (1993) Sharma and Gupta (2001)
				b) Cowpea-wheat	40	
				Bajra + cluster bean or mungbean	15	
X	Andhra Pradesh, Karnataka, Tamil Nadu	Alluvial	Hyderabad	Intercropping		Patil <i>et al.</i> (1979)
				Pigeonpea + groundnut	46	
				Pigeonpea + cowpea (F)	46	
XI	Andhra Pradesh, Karnataka, Tamil Nadu	Alluvial	Hyderabad	Pigeonpea + urd bean	85	De <i>et al.</i> (1983)

\*F; fodder

It is also reported that intercropping of maize with black gram/green gram, cowpea, groundnut, or soybean has beneficial as well as adverse effect on main crop. The yield of maize in an intercropping system with legumes may increase (Patra *et al.*, 1999; 2000; Shivay *et al.*, 1999) or decrease (Allen and Obura, 1983; Siddeswaran *et al.*, 1989; Maitra *et al.*, 2000) depending upon the planting geometry, competitive ability, kind of crop grown, and weather conditions, etc. (Sharma and Behara, 2009). Growing cowpea and groundnut has been proved to be more compatible with maize, causing no adverse effect on its performance. Yield of maize is not affected due to intercropping with black gram, green gram and soybean because of better compatibility of their varieties (Sharma and Behara, 2009).

In pigeonpea, intercropping of different pulse crops has variable response under different agro-ecological zones. Intercropping of pigeonpea with mungbean is reported to produce higher equivalent over sole crop of pigeonpea in North West Plain Zone of the country, while in Central Zone intercropping with groundnut or soybean is better and in South Zone mungbean or urd bean intercropping is reported to have higher pigeonpea equivalent yield (Anonymous, 2004). Ahlawat and Shivakumar (2005) suggested that crop having differing growth stages, growth pattern and growth duration, avoidance of competition for resources at the critical stage of growth, in general, makes a suitable component crop for intercropping with pigeonpea. More over, plant type differing in height, branching habit, canopy cover and crop duration decides the suitability for intercropping system.

Incorporation of residues of pulse crops is reported to have beneficial effect to wheat. It is estimated that nitrogen economy in wheat due to incorporation of residue of intercropped green gram, cowpea and groundnut is 21 kg N/ha, and due to sole crop of green gram and groundnut is 49-56 kg N/ha. Residual soil fertility, in terms of organic carbon and  $\text{KMNO}_4\text{-N}$  is shown to be improved under maize based intercropping system followed by wheat, and the beneficial effect is reported to be more pronounced with sole cropping of legumes due to greater addition of crop residues. Apparent nitrogen balance as well as actual changes in  $\text{KMNO}_4\text{-N}$  at the end of study has been reported to be positive in most intercropped legumes as well as sole cropping systems, with greater improvement noticed under groundnut, soybean and green gram. It is suggested that inclusion of grain legumes, particularly green gram, cowpea and groundnut in maize-wheat cropping system, is beneficial for improving productivity, profitability, N economy and soil fertility. Maize equivalent productivity is reported to be significantly more with intercropped green gram (16.1-29.9%), cowpea (24.8%) and groundnut (11.1-16.6%) than that obtained for sole maize crop (Sharma and Behara, 2009).



There is a considerable improvement in yield of main crop due to incorporation of legume biomass under rainfed condition. The beneficial effect of summer legume is more evident at low nitrogen rates of N application (Sharma and Behara, 2009). There is a direct addition of nitrogen through above ground biomass, but the legumes may enhance the soil available nitrogen pool for following crops via root exudates or inefficiencies in recovering soil mineral nitrogen during the legume phase, and subsequent decomposition of root and nodules residues (Ghosh and Singh, 1994; Herridge *et al.*, 1995; Ghosh *et al.*, 2007). Such indirect additions of N contribute to substantial saving of N fertilizers and enrich soil fertility even when all the legumes residues have been removed from the field (Kumar and Prasad, 1999; Sharma, 2005a; 2005b; 2005c). Crew and Peoples (2005) reported that the legume crops recover more N from fertilizer but a higher proportion of plant N is retained in the soil. Losses of N are much higher from the urea fertilizer applied to the soil than from N added to the soil by legume residues or green manures (Jensen and Hauggaard-Nielson, 2003). Most of the studies on the fate of  $^{15}\text{N}$  labeled fertilizers or legume residues indicate that 10-30% of the legume N is commonly taken by the subsequent crop, whereas the recovery by the successive crop is >15-20% of that remained in the soil (Fillery, 2001; Krupnik *et al.*, 2004). Combined use of organic and mineral N ensures prolonged availability of N; even beyond the growth period of maize crop and its residual effect on subsequent wheat crop as well (Sharma and Behara, 2009).

### STABLE RETURN AND MORE RISK COVERAGE

Intercropping of pulses with cereals, pulses and oilseeds lowers the risk of failure of crop; even if one crop fails it may be compensated by the companion crop grown in the season. While examining the stability of sole and intercropping systems, pigeonpea/sorghum intercropping fails less often than either sole crop or shared sole system where a farmer grows same as each sole crop. Taking disaster levels of Rs.1000 ha<sup>-1</sup> as an example, sole pigeonpea fails once in 5 years, sole sorghum once in 8 years, shared sole once in 13 years and intercropping only once in 36 years. An other second stability mechanism widely believed is that under stress condition intercropping can give a relatively greater yield advantage, resulting in less yield depression than sole cropping (Sekhon and Singh, 2005).

### Energy Use Efficiency of Intercropping

Intercropping of pulses with cereals and oilseed crops, and use of legumes in cropping system has a great advantage towards nitrogen economy and energy saving. In such systems, nitrogen economy is reported to vary from 20 to 68 kg N/ha, and energy saved from 14 to 54 × 10<sup>8</sup> Joules per hectare (Saraf and Patil, 1995) (Table 3).

**Table 3.** Nitrogen economy and energy saved by different legume based cropping systems

Cropping system	N economy (kg/ha)	Energy saving ( $\times 10^8$ J/ha)
Chickpea-maize	56-68	45-54
Chickpea-pearlmillet	40	32
Lentil-maize	18-3	14-24
Lentil-pearlmillet	40	32
Peas-maize	20-32	16-25
Peas-pearlmillet	40	32
Lathyrus-maize	36-48	29-38

Source: Saraf and Patil, 1995

In an experiment with maize intercropped with green gram or black gram in different row proportion revealed that intercropping of maize with normal row planting, irrespective of intercrop, produced higher total output energy ( $203.63 - 209.69 \times 10^3$  MJ ha<sup>-1</sup>). However, the energy use efficiency of maize + green gram/black gram in normal row planting with a row ratio of 1:1 has been the highest (Tripathi *et al.*, 2010).

**Table 4.** Energy-use efficiency by sole crop and when intercropped in different row proportions

Treatment/ row proportion	Energy input MJ ha <sup>-1</sup>	Energy output MJ ha <sup>-1</sup>	Net energy output MJ ha <sup>-1</sup>	Energy use efficient	Energy productivity (g MJ <sup>-1</sup> )
Sole maize (60 cms)	11,957	1,68,661	1,56,704	14.10	264
Urd bean	5,248	32,778	27,538	6.24	399
Mung bean	5,216	39,104	33,888	7.49	440
Maize + urd bean (1:1)	13,397	1,96,551	1,83,154	14.67	323
Maize + urd bean (1:2)	14,769	2,03,625	1,88,856	13.78	342
Maize + urd bean (2:1)	12,588	1,71,660	1,59,072	13.63	284
Maize + urd bean (2:2)	13,201	1,86,755	1,73,554	14.14	319
Maize + mung bean (1:1)	13,381	2,03,465	1,90,084	15.20	332
Maize + mung bean (1:2)	14,738	2,09,694	1,94,956	14.22	361
Maize + mung bean (2:1)	12,564	1,70,267	1,57,703	13.55	286
Maize + mung bean (2:2)	13,178	1,86,467	1,73,289	14.13	328

Source: Nedinchezhiyan, 2007

A row ratio of 1:2 for maize + legume intercropping systems with normal row planting (60 cm) has been reported to be the best for the maximum energy use efficiency (Table 4). As indicated in Table 4, the higher amount of energy productivity was recorded with maize + legume in a row ratio of 1:2 (342 to 361 g/MJ). Intercropping with paired row



planting in a row proportion of 2:1 irrespective of intercrop resulted in lower energy used and energy productivity (Nedinchezhiyan, 2007).

### Shading and Competition Stress

In general chickpea-wheat intercropping is advantageous because canopy development and dry matter production is slow in chickpea. Further, chickpea being an indeterminate crop, flowering followed by pod formation is generally initiated much before the maximum canopy development. LAI in chickpea is between 2 to 4. Wheat, being a determinate crop, the maximum LAI is achieved just before the onset of the reproductive phase. In chickpea genotype, JG-62, the LAI remains less than one at 80 DAS; when flowering commences, and it reaches to about 3 when pod formation starts at 100 days after sowing, which is much earlier than the attainment of the maximum LAI by wheat crop. Therefore, light interception is not a problem in chickpea and wheat when they are taken in intercropping. Moreover, leaves of wheat are erect, whereas in chickpea leaves are pinnate and parallel to the ground. Chickpea has a tap root system that extracts moisture and nutrients from the deeper soil zones, while wheat roots do not go so deeper in the soil. Crown roots and nodal roots in wheat are mostly surface feeders, hence not competing with the chickpea roots for nutrients, moisture and organic contents.

In pigeonpea + sorghum/pearlmillet cropping system, leaf area development rate and leaf expansion rate is very high relative to sorghum or pearlmillet. The LAI increases with slower rate during early phase of growth in the long/medium duration pigeonpea genotypes, hence initially dry matter production is also low in them (Sheldrake and Narayanan, 1979). Leaf area index increases exponentially unless canopy starts to close, and at this stage accumulation of biomass is a linear function of amount of photosynthetically active radiation intercepted by the crop canopy (Hughes *et al.*, 1981; Hughes and Keatinge, 1983). Interception of photosynthetically active radiation by reproductive structure is more in determinate types with apical inflorescence, but there is interference in light interception when such genotypes are grown along with sorghum. Such competition is less when indeterminate genotypes of pigeonpea are taken for intercropping with sorghum, because by the time the growth picks up in indeterminate pigeonpea genotypes, the sorghum crop matures. The pigeonpea is the most sensitive crop to low radiation during the period of pod formation (Thiraton *et al.*, 1987); therefore, while selecting crop for mixed cropping with pigeonpea, the companion crops should be a least photo-competitive crop and cropping geometry is also to be adjusted accordingly to minimize the competition for light.

Intercropping cereals with pulses or pulses with pulses is advantageous as such practices suppress the growth of weeds. Weeds compete for nutrients, moisture, sunlight and space for their survival, and also reported to secrete some allelochemical that affect growth and development of main

crops. Intercropping of maize with legumes in a crop row ratio of 1:1 or 1:2 reduced the weed population and weed dry matter accumulation. The reduction in weed density and weed dry matter in intercropping system has been attributed mainly due to shading effect and competitive stress created by crops that is having suppressive effect on associated weeds, thus preventing the weeds to attain full growth (Tripathi *et al.*, 2010).

### Disease/Insect Control in Intercropping System

It has been observed that in pigeonpea and sorghum intercropping, the control of *Fusarium udum* wilt is achieved. Root exudates of sorghum help in reducing the spread of *F. udum*. When cotton is raised with *Vigna aconitifolia*, the root rot of cotton has been reported. Crops found suitable for adaptation in the rotations or intercropping with pigeonpea are cereals, sorghum and *Crotalaria medicaginea* (Bose, 1938; Upadhyay and Rai, 1981), and among these sorghum as mixed crop, intercrop or as crop rotation is most effective. Allowing the sorghum stalk unharvested after the cob has been harvest, further improves the efficacy against *F. udum* (Chaudhary, 1998). Some reports are there to indicate the control of pod fly attack on pigeonpea when intercropped with cereals. Preliminary works on intercropping of pigeonpea with marigold, *Solanum viarum*, cowpea and sorghum genotypes of similar maturity duration have indicated some control of pod fly (Hegde and Lingappa, 1996; Mohammed and Rao, 1998); however,, such observations need revalidation (Lal *et al.*, 2005).

### REFERENCES

- Ahlawat, I. P. S. and Shivkumar, B. G. 2005. Cropping system research in pigeonpea. *In: Proceedings of National Symposium on Pulses for Sustainable Agric & Nutritional Security*, 17-22 April, 2001 Ali M., Chaturvedi S. K. and Gurha S. N., (Eds). IARI, New Delhi & ISPRD, Kanpur, India, pp. 23-32.
- Ali, M. 1992. Effect of summer legumes on productivity and N economy of succeeding rice in sequential cropping. *Indian J. Agric. Sci.* **62**: 466-67.
- Allen, J. R. and Obura, R. K. 1983. Yield of corn, cowpea and soybean under different intercropping systems. *Agron. J.* **75**: 1005-9.
- Anonymous. 2004. Annual Report. Indian Institute of Pulses Research, Kanpur.
- Askok Kumar and Balyan, J. S. 2002. Effect of kharif treatment/legume management on succeeding wheat and soil properties. *In: National Symposium on Agriculture in Changing Global Scenario*, 21-23 February 2003, IARI, New Delhi, India, pp. 173.
- Baghel, R. S. 2005. Nirtogen requirement of wheat after kharif legume and cereals. *Indian J. Pulses Res.* **18**: 224-25.
- Bose, R. D. 1938. The rotation of tobacco for the prevention of wilt disease of pigeonpea (*Cajanus cajan* (L.) Millsp.). *Agic & Live Stock India.* **8**: 653-68.



- Chaudhary, R. G. 1998. Epidemiology and management of wilt of pigeonpea (*Cajanus cajan*) caused by *Fusarium udum* Butler, Ph. D. Thesis, CSA Univ. Agric. & Tech., Kanpur, India.
- Crews, T. E. and Peoples, M. B. 2005. Can the synchrony of nitrogen supply and crop demand be improved in legume and fertilizer-based agroecosystem? A review. *Nutr. Cycl. Agroecosys.* **72**: 101-20.
- De, R.; Yogeshwar Rao and Ali, W. 1983. Grain and fodder legumes as preceding crops affecting the yield and N economy of rice. *J. Agric Sci.* **101**: 463-66.
- Fillery, I. P. R. 2001. The fate of biologically fixed nitrogen I. Legume based dry land farming systems. A review. *Australian J. Exp. Agric.* **41**: 361-81.
- Ghosh, P. K. and Singh, N. P. 1994. Soil nitrogen status under summer legume maize sequence. *Indian J. Agric. Sci.* **64**: 856-57.
- Ghosh, P. K.; Bandypadhyay, K. K.; Wanjari, R. H.; Manna, M. C.; Mishra, A. K. and Mohanty, M. 2007. Legume effect for enhancing productivity and nutrient use efficiency in major cropping systems: An Indian perspective-A Review. *J. Sustain. Agric.* **30**: 61-86.
- Giri, G. and De, R. 1981. Short season fodder legume affects on grain yield and nitrogen economy of barley under dry land condition. *J. Agric. Sci.* **96**: 457-61.
- Gogoi, H. N. and Sandhu, H. S. 1984. Fertilizer requirement of wheat grown after different kharif crops. *Indian J. Agron.* **29**: 15-19.
- Hegde, R. and Lingappa, S. 1996. Effect of intercropping on incidence and damage by *Helicoverpa armigera* in pigeonpea. *Karnataka J. Agric. Sci.* **9**: 616-21.
- Herridge, D. F.; Marcellos, H.; Felton, W. L.; Turner, G. L. and People, M. B. 1995. Chickpea increases soil N-fertility in cereal system through nitrate spraying and N fixation. *Soil Biol. Biochem.* **27**: 545-51.
- Hughes, G. and Keatinge, J. D. H. 1983. Solar radiation interception, dry matter production and yield of pigeonpea (*Cajanus cajan* (L.) Millsp.). *Field Crop Res.* **6**: 171-78.
- Hughes, G. G.; Keatinge, J. D. H. and Scott, S. P. 1981. Pigeonpea as a dry season crop in Trinidad, West Indies. II. Interception and utilization of solar radiation. *Trop. Agric. (Trinidad)*. **58**: 191-99.
- Jensen, E. S. and Hauggaard-Nielsen, H. 2003. How can increased use of biological nitrogen fixation in agriculture benefit the environment? *Plant Soil.* **252**: 177-86.
- Krupnik, T. J.; Six, J.; Ladha, J. K.; Paine, M. J. and van Kessel, C. 2004. An assessment of fertilizer nitrogen recovery efficiency by grain crops. *In*:

*Agriculture and the Nitrogen Cycle*, Mosier A. R., Syers K. J. and Freney J. R., (Eds). The Scientific Committee on Problems of the Environment (SCOPE). Island Press, Covelo, California, USA, pp. 197-207.

Kumar, S. and Prasad, N. K. 1999. Energetics and economics of cropping sequences and nitrogen levels. *Indian J. Agron.* **44**: 677-80.

Lal, S. S.; Srivastava, C. P. and Rai, A. B. 2005. Insect pests of pigeonpea and their management. *In: Advances in Pigeonpea Research*. Ali M. and Kumar Shiv, (Eds). IIPR, Kanpur, India, pp. 262-83.

Lee, K. K. and Wani, S. P. 1989. Proceeding of Collogium on Soil Fertility and Fertilizer Management in Semiarid Tropics of India. IFDC Muscle Shoals. AL, pp. 89-108.

Maitra, S.; Ghosh, D. C.; Sounda, G.; Jana, P. K. and Roy, D. K. 2000. Productivity, competition and economics of intercropping legumes in finger millet (*Eleusine ceracoma*) at different fertility levels. *Indian J. Agric Sci.* **70**: 824-28.

Mohammad, G. and Rao, A. S. 1998. Influence of intercrops on the incidence of *Helicoverpa armigera* (Hubner) in pigeonpea. *International Chickpea & Pigeonpea News Letter.* **6**: 46-47.

Nedunchezhiyan, M. 2007. Production and energy use efficiency of great yam (*Dioscorea alata*) based intercropping system as influenced by intercrop and planting pattern. *Indian J. Agron.* **52**: 216-19.

Patil, B. B.; Shinde, S. H. and Patil, D. F. 1979. Nitrogen requirement of wheat as influenced by intercropping by preceding kharif legumes. *J. Maharashtra Agric. Univ.* **4**: 49-55.

Patra, B. C.; Mandal, B. B.; Mandal, B. K. and Padhi, A. K. 1999. Suitability of maize based intercropping system. *Indian J. Agric. Sci.* **69**: 759-62.

Patra, B. C.; Mandal, B. B.; Mandal, B. K. and Padhi, A. K. 2000. Production potential of maize based cropping system. *Indian J. Agric. Sci.* **70**: 202-6.

Saraf, C. F. and Patil, R. R. 1995. Fertilizer use in pulse based cropping system. *Fertilizer News.* **40**: 55-56.

Saraf, C. S. 1981. Consolidated report on agronomy of pulse crop. AICPIP Workshop, IARI, New Delhi, India.

Saxena, M. C. and Tilak, K. V. B. R. 1975. Response of inoculation in soybean and its residual effect on wheat. *Indian J. Agron.* **20**: 369-70.

Sekhon, H. S. and Singh, Gur Iqbal. 2005. Agronomic research and management in pigeonpea. *In: Advances in Pigeonpea Researches*. Ali M. and Kumar Shiv, (Eds). IIPR, Kanpur, India, pp. 144-63.

Sharma, A. R. and Behara, U. K. 2009. Recycling of legume residues for nitrogen economy and higher productivity of maize (*Zea mays*)-wheat cropping system. *Nutr. Cycl. Agroecosyst.* **83**: 197-210.



- Sharma, O. P. and Gupta, A. K. 2001. Performance of pearl millet in different intercropping system with varying levels of fertility. *Ann. Agric. Res. News Letter*. **22**: 267-70.
- Sharma, S, N, 2005a. Integrated nutrient management in rice-wheat cropping system. *Fert. News*. **50**: 53-58.
- Sharma, S, N, 2005b. Integrated nutrient management in rice-wheat cropping system. *Fert. News*. **50**: 61-64.
- Sharma, S, N, 2005c. Integrated nutrient management in rice-wheat cropping system. *Fert. News*. **50**: 71.
- Sheldrake, A. R. and Narayanan, A. 1979. Growth, development and nutrient uptake in pigeonpea. *J. Agric. Sci.* **92**: 513-26.
- Shivay, Y. S.; Singh, R. P. and Madan Pal. 2001. Productivity and economics of maize as influenced by intercropping with legumes and N levels. *Ann. Agric. Res. News Series*. **22**: 576-82.
- Shivay, Y. S.; Singh, R. P. and Pandey, C. S. 1999. Response of nitrogen in maize-based intercropping system. *Indian J. Agron.* **44**: 261- 66.
- Siddeswaran, K.; Ramaswami, C.; Morachan, Y. B. 1989. Nutrient up take of finger millet as influenced by intercrops, border crops and N fertilization. *Modern Agric. J.* **76**: 361-65.
- Singh, S. B. and Verma, B. S. 1985. Effect of kharif grain legumes on N economy in succeeding crop of wheat. *Indian J. Agron.* **31**: 380-83.
- Singh, V. K. and Bajpai, R. P. 1993. Effect of kharif legumes on productivity and N economy in succeeding wheat. *Indian J. Pulses Res.* **6**: 202-4.
- Sinsinwar, B. S. 1993. Sequential and parallel fodder production in wheat based cropping system with special reference to N economy. *Indian J. Agron.* **38**: 531-35.
- Srivastava, G. P. and Srivastava, V. C. 1993. Effect of winter legumes on N economy of succeeding rice. *Indian J. Agric. Sci.* **63**: 501-3.
- Subbarao, N. S. 1988. *Biological Nitrogen Fixation: Recent Developments*. Oxford, & IBH. pp. 1-19.
- Thirathon, A.; Byth, D. E.; Fischer, K. S. and Whiteman, P. C. 1987b. Relationship between leaf area, radiation interception and dry matter production after flowering in short season pigeonpea. In: *Food Legume Improvement for Asian Farming Systems*. Willis E. S. and Byth Khon Kaen D. E., (Eds). Australian Centre for International Agricultural Research (ACIAR), Department of Agriculture, Thailand, Faculty of Agriculture, Khon Kaen University, Thailand, pp. 252-53.
- Tripathi, A. K.; Shukla, N. S.; Kumar, K. and Pandey, S. N. 2010. Production potential, weed dynamics and energetics of maize + green gram, black gram intercropping system. *J. Food Legume*. **23**: 30-34.

Upadhyay, R. S. and Rai, B. 1981. Effect of cultural practices and soil treatments on incidence of wilt disease of pigeonpea. *Plant Soil*. **62**: 309-12.

Venkateswarulu, J. 2004. Integrated soil productivity management systems. *In: Proceedings of 69<sup>th</sup> Annual. Convention of the Indian Society of Soil Science*. 27-30 October 2004, p27.

Yadav, D. S. and Singh, S. B. 1986. Studies in nitrogen economy in legume based cropping system. *Indian J. Agron.* **44**: 261-66.

Yadav, D. S. 1990. Studies on nitrogen economy through mungbean and urdbean legumes in legume-cereal cropping system. *Legume Res.* **13**: 65-68. ●



## CHAPTER 8

# Physiology of Chickpea

Chickpea (*Cicer arietinum* L.) is the third most important food legume grown globally. It is known as Bengal gram or Garbazo bean, and belongs to family Fabaceae, subfamily Faboideae. It is also called as *Chana* in northern states of India, *Chhole* in Punjab, *Chola* in West Bengal, *Boot* in Orissa, *Sanagulu* in Andhra Pradesh, *Kadale* in Karnataka, *Kadalai* in Tamil Nadu and *Kadala* in Kerala. Genus *Cicer*. Its botanical name is *Cicer arietinum*. Chickpea is a self-pollinating crop with  $2n=16$ ,  $IC=931\text{mbp}$ . These are two main types of chickpea; *desi* and *kabuli* types. The *desi* types are smaller in size, having darker and a rough seed coat, and cultivated mostly in the Indian sub-continent, Ethiopia, Mexico and Iran. Whereas *kabuli* types are having larger seed size, white or cream coloured and smoother seed coat. *Kabuli* types are, mainly grown in southern Europe, Northern Africa, Afghanistan, Pakistan and Chile, and introduced in the 18<sup>th</sup> century to the Indian sub-continent. It is known by different names in India.

Chickpea is mainly used for human consumption and only a small proportion is used as feed. The *kabuli* type is generally used as whole grains while *desi* type is used as whole seed, dehulled splits (*dal*) or as flours. Chickpea is also known for its use in herbal medicine and cosmetics. Chickpea seeds are rich in dietary fibre, and hence are a healthy source of carbohydrate for persons with insulin sensitivity or diabetes. They can help a lot in reducing cholesterol and also in preventing the blood sugar level from rising too much immediately after the meal. Chickpea seeds are a good source of zinc, folic acid and protein. Being rich source of molybdenum, it helps in detoxifying sulphates which can otherwise cause rapid heart beats or headache in sulphate sensitive people, if consumed in larger quantities. Too much reaction to sulphite is caused mainly due to the lack of molybdenum to detoxify sulphite. The chickpea seeds are low in calories, and are virtually fat free, and having high proportion of polyunsaturated fatty acids. It is also very high in trace minerals like manganese, which is important for energy producing enzymes. Iron also helps in improving the hemoglobin level, thereby, improving flow of blood. It does not contain any anti-nutritional factor. Chickpea seeds contain 23% protein, 64% total carbohydrates, 47%, starch, 6% soluble sugar, 5% fat, 6% crude fiber, and 3% ash. It is high in phosphorus, calcium, magnesium and zinc. Digestibility of chickpea proteins is the highest

among all edible legumes. The lipid fraction is high in unsaturated fatty acids, primarily linolic and oleic acid. Nutritional values of chickpea seeds as well as dal (split cotyledons without seed coat) are given in Table 1.

**Table 1.** Nutritional value of chickpea (100g/seed)

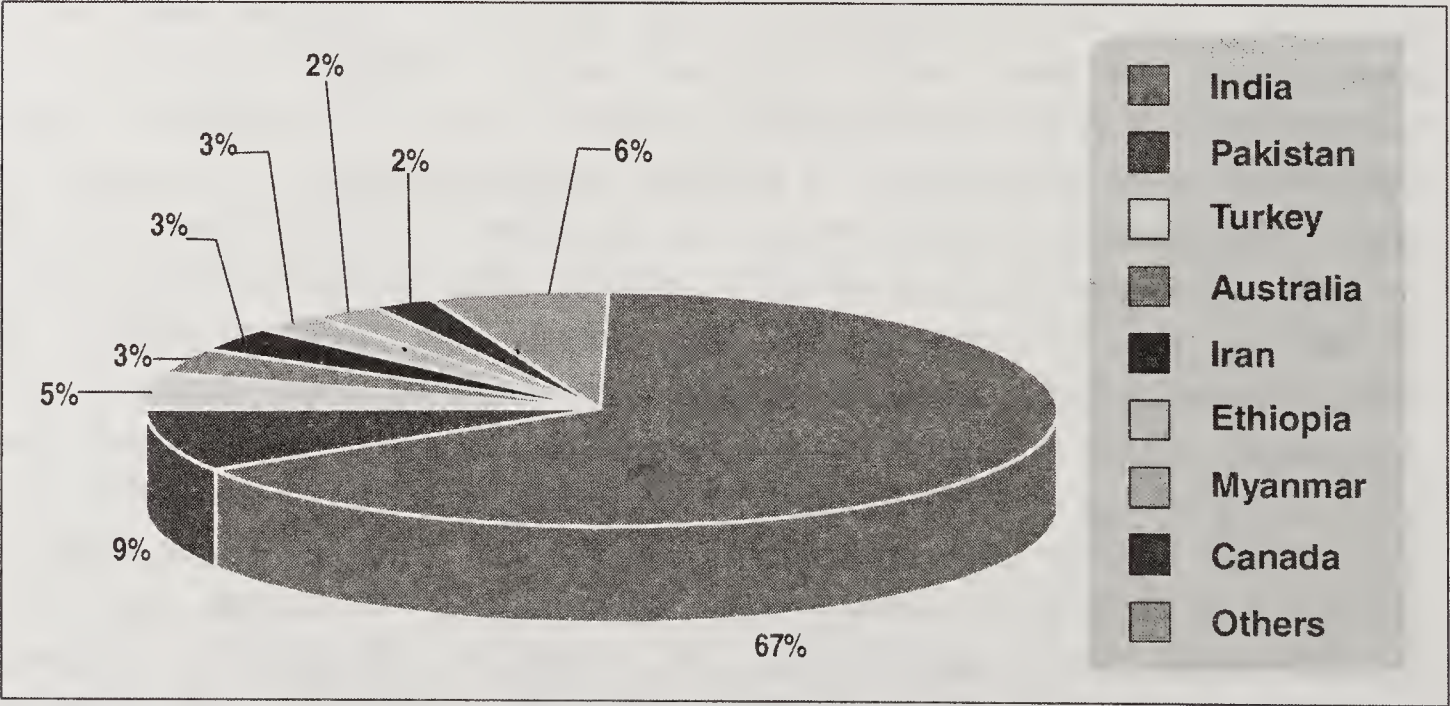
Component	Chickpea (whole)	Chickpea (dal)
Energy (cal)	360.00	372.00
Protein (g)	17.10	20.80
Fat (g)	5.30	5.60
Calcium (mg)	202.00	56.00
Iron (mg)	10.20	9.20
Thiamin (mg)	0.30	0.48
Riboflavin (mg)	0.15	0.18
Niacin (mg)	2.90	2.40
Vitamin C	3.00	1.00
Vitamin A µg	189.00	129.00

Source: Gopalan *et al.* 1985

**Area, Production and Productivity**

Production as well as consumption of chickpea in India is the maximum, and it is followed by Pakistan, Turkey, Australia, Iran, Myanmar, Canada, Ethiopia, Mexico and Iraq. At global level the contributions of different countries in chickpea production are; India 67%, Pakistan 9%, Turkey 5%, Australia 3%, Iran 3%, Ethiopia 3%, Myanmar 2%, Canada 2% and Mexico 2% (Fig. 1).

**Fig. 1:** Contribution of different countries in chickpea production



Source: Anonymous, 2007a.



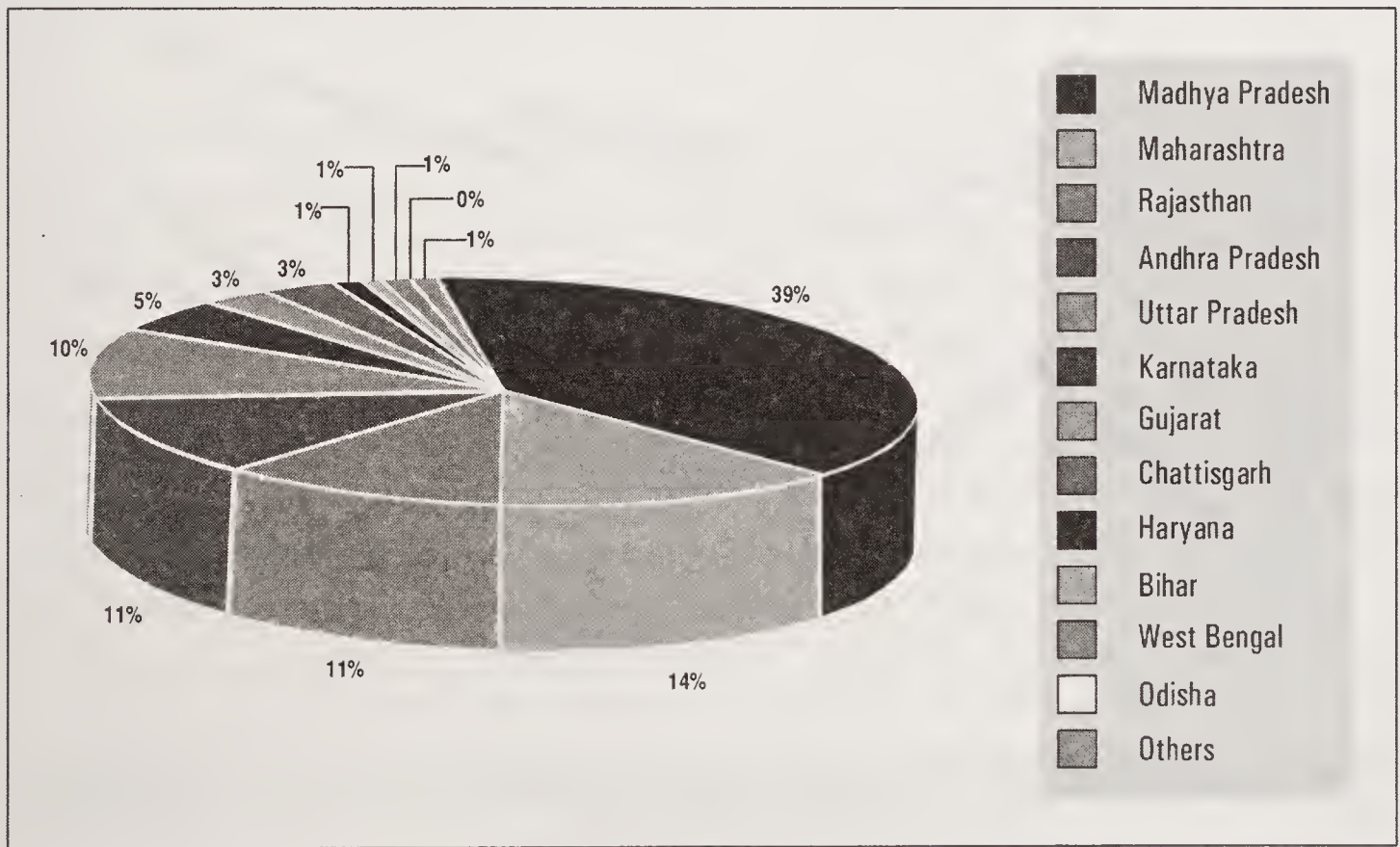
Chickpea Producing States in India

In India, chickpea is primarily grown in Madhya Pradesh (39%), Maharashtra (14%), Uttar Pradesh (10%), Andhra Pradesh (11%), Rajasthan (11%), Karnataka (5%), Chhattisgarh 3%), Gujarat (1%), Haryana (1%) and Bihar (1%) (Fig. 2).

**Madhya Pradesh:** It is the main chickpea producing state in India. In 2008-09 the area under chickpea cultivation was 26-28 lakh ha, and around 24 lakh tonnes of *chana* has been produced, predominantly in Narsinghpur, Sagar, Ujjain, Shajapur, Vidisha, and Indore districts. Most of the farmers preferred to grow *kabuli chana* than *desi chana*. During 2008-09 production of *kabuli chana* was 5-7 lakh tonnes as compared to 1.5 lakh tonnes in 2007-08.

**Rajasthan:** It is second largest chickpea producing state in the country and during 2008-09 nearly 10 lakh tonnes chickpea has been produced in this state. Cropped area and production in the state depends on weather conditions, as it is grown under rainfed condition. Sriganganagar and Jaipur regions are the main chickpea-growing areas. It is also cultivated in Sriganganagar, Bikaner, Churu and Hanumangarh districts of the state.

**Fig. 2.** Area under chickpea cultivation (per cent of total) in major chickpea-growing states of India



Source: Anonymous (2008)

**Uttar Pradesh:** It is grown in southern part of the state, but here quality of produce is poor because of some toxic substances. In this state, 5.25 lakh tonnes of chickpea was produced during 2008-09, primarily in Kanpur, Allahabad, Jhansi and Chitrakut districts. In irrigated areas chickpea is being replaced by wheat.

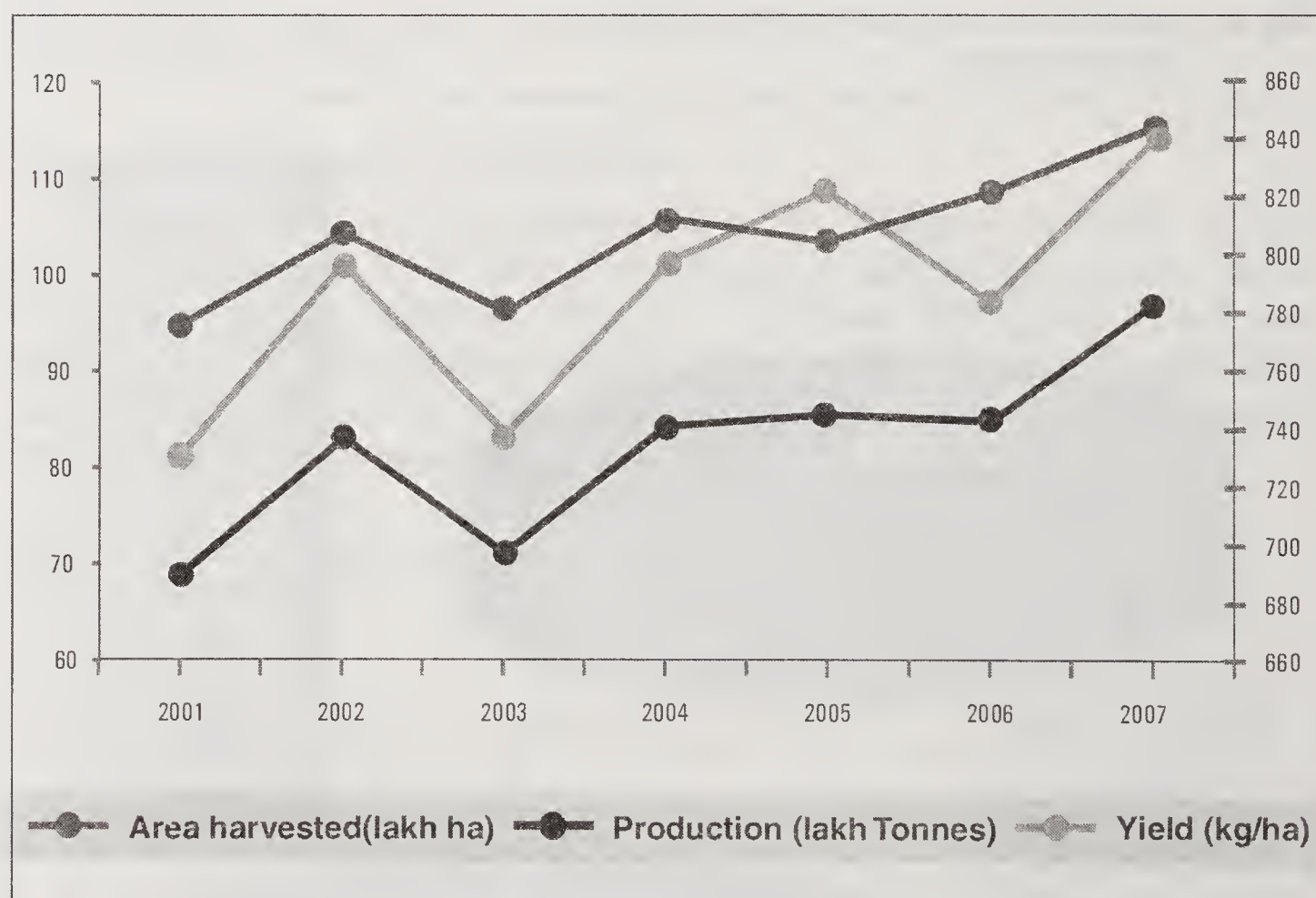
**Maharashtra:** This state of India is famous for production of good quality chickpea. Yield and quality of the produce from Jalagaon, Amaravati, Akola, Ahmednagar, Latur, Osmanabad and Salapur districts are good. In 2008-09 state produced 6.0 lakh tonnes of chickpea.

**Karnataka:** It has produced 3.54 lakh tonnes of chickpea in 2008-09. Main districts producing chickpea in the state are Gulburga, Belgam, Bidar, Bijapur, Dharwad and Gadag. In this state crop production solely depends upon rainfall, and sometimes heavy rainfall damages the crop.

**Andhra Pradesh:** Telangana is the main region for chickpea growing in the state and now it is gaining ground for enhanced productivity due to the availability of short duration, high yielding and *Fursarium* wilt resistant varieties.

**Gujarat:** It is a leading consumer of chickpea in India. The main chickpea producing areas are Dohad, Jamnagar, Kutch, Saurashtra and the northern part of the state. Yield as well as quality of produce is the best among all the states in India. (Shaha and Agarwal, 2010).

**Fig. 3.** Changes in total production, productivity and area under chickpea production in India from 2001-2007



Source: Anonymous (2007a)

Production, productivity and area under chickpea cultivation in India from 2001-2007 are depicted in Fig. 3. In India the total production of chickpea is now showing a declining trend. It was 6.8 million tonnes in 1998-99 with a share of 72.11% of total world production, but in 2008-09 it came down to 65.62%. Year-wise variations in area under chickpea cultivation, its total production and productivity per ha from 1950-51 to



2009-10 are depicted in Table 2. This table also shows per cent of total cultivated area under irrigated condition.

**Table 2.** Year-wise variations in area under chickpea cultivation in India, its production per ha productivity from 1950-51 to 2009-10. Table also shows per cent of total cultivated area under irrigated condition.

Year	Area (m ha)	Total production (million tonnes)	Productivity (kg/ha)	Area under irrigated condition
1950-51	7.57	3.65	482	12.5%
1960-61	9.28	6.25	674	11.9%
1970-71	7.84	5.20	663	15.6%
1980-81	6.58	4.33	657	20.6%
1990-91	7.52	5.36	712	20.5%
2000-01	5.19	3.86	744	30.9%
2002-03	5.91	4.24	717	32.1%
2004-05	6.71	5.47	815	NA
2006-07	7.63	5.97	782	NA
2008-09	7.50	6.38	850	NA
2009-10	-	8.00	-	NA

In India, population is growing at a faster rate than the production of chickpea, hence to meet out the domestic demand India is importing the *desi chana* from Australia (42%), Myanmar (23.33%), Tanzania (11.35%), Canada (3.8%) and other countries 19.02%.

Although India is importing chickpea and other pulses, but the import of chickpea has declined since 2001-02. Out of total pulse imported, the import of chickpea has been 23.3% in 2003-04, 15.04% in 2004-05, 16.6% in 2005-06, 5.61% in 2006-07, and 5.22% in 2007-08. This downward trend is mainly attributed to the increased use of yellow pea for *besan* at the place of chickpea. On the other hand the export of chickpea has shown increasing trend. Out of total pulses exported, the contribution of chickpea was 0.88 % in 2001-02, which has increased to 1.89% in 2003-04. There are two possible reasons for increase in export of chickpea. One being the ban on the export of pulses by the Government of India except that of *kabuli chana*, and the second is an increase in demand of *kabuli chana* in the international market, mainly in the Western countries, which has encouraged farmers to grow more *kabuli chana* over the years.

In 1964-65, chickpea area in Northern and North Eastern states of India was about 5.147 m ha (Punjab 0.744, Haryana 1.310, Uttar Pradesh 2.627 and Bihar 0.466 m ha). During 2005-06 this reduced to 0.956 m ha. The reduction has been 0.004 m ha in Punjab, 0.146 m ha

in Haryana, 0.74 m ha in Uttar Pradesh and 0.066 m ha in Bihar. Fortunately, the reduction in area has been partly compensated by increase in area under chickpea cultivation in Central and Southern India (Anonymous, 2007b). Area under chickpea cultivation in Central and Southern India was about 2.050 m ha (Madhya Pradesh 1.468, Maharashtra 0.359, Andhra Pradesh 0.076, Karnataka 0.146m ha) in 1964-65, but it has increased to 4.665 m ha (Madhya Pradesh 2.561, Chhattisgarh 0.232, Maharashtra 1.088, Andhra Pradesh 0.394, and Karnataka 0.390 m ha) in 2005-06.

Andhra Pradesh which was once not considered as a suitable region for chickpea cultivation due to mild and short winter season has now become the leading state in chick pea production in the country. There has been nearly 5 fold increase in area under chickpea cultivation and 13 fold increase in its production from 1993 to 2002. Productivity also increased from 468 kg/ha to 1274 kg/ha. It has been possible because of availability of short duration varieties, and adoption of appropriate production technologies suitable for relatively warmer and short season environments. Introduction of *Fusarium* wilt resistant varieties (ICCV 2, ICCV 92311, ICCV 37 and ICCV 93954 in *kabuli* types) has further boosted yield in this part of the country. Because of the work carried out at ICRISAT there has been possibilities that cultivation of *kabuli* types, which fetches up to two times more price than *desi* types, could be extended for the first time in tropical latitude (Anonymous, 2007b).

### Leaf Area Development and Light Interception

Compared to other legumes, canopy development and dry matter production in chickpea are rather slow. It is an indeterminate crop, therefore, flowering followed by pod formation may occur much before full canopy development. Leaf area index (LAI) in chickpea ranges between 2 and 4. In determinate type of crops such as wheat, the maximum LAI is achieved before the onset of reproductive phase. Thus, availability of photosynthates to developing grains in wheat is likely to be maximized due to full light interception at maximum LAI. On the contrary, once flowering has initiated further flowering and podding in most of the chickpea genotypes goes on simultaneously throughout the crop period of about 120-130 days. Therefore, reproductive phase rarely coincides with maximum LAI attainable for a genotype and hence, seed development process does not get opportunity to take advantage of full light interception. Again, the LAI and light interception varies from one genotype to another and also depends upon the geographical location and soil moisture condition. The LAI under rainfed condition is lower than that under irrigated condition. Hence, under moisture limiting condition light interception is not up to the fullest extent. For example, the LAI remains less than 1.0 even after 80 days of sowing in genotype JG-62 when flowering commences (Aggarwal *et al.*, 1984). The LAI reaches to about 3 when pod formation starts at 100 days after sowing (DAS).



## Photosynthesis

Chickpea is a  $C_3$  plant. However, there is one report on CAM-like behaviour in chickpea (Shantakumari *et al.*, 1979). Photosynthetic rate of the crop varies from 6.0 to 24.0  $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$  under water stressed and well watered conditions (Ma *et al.*, 2001), respectively, which is comparable to other  $C_3$  species. However, van der Maesen (1972) and Sinha (1977) indicated that photosynthetic rates of chickpea are much better than those in soybean, lentil, dry bean, cowpea, and red clover. Photosynthetic rates are found to be the maximum in 2 week-old leaves (van der Maesen, 1972). Prasad *et al.* (1978) observed large genotypic variation for photosynthetic efficiency in leaves, stem and pods of chickpea, which together contribute towards grain yield. Khanna-Chopra and Sinha (1982) emphasized the importance of photosynthetic potential of pod wall towards seed development. Internal re-cycling of  $\text{CO}_2$  inside the pod contributes in maintaining seed filling, particularly under water stress condition (Ma *et al.*, 2001). The developing pod gets most of the photosynthates from the subtending leaf (Pandey *et al.*, 1978). When there is no axillary pod the photosynthates are diverted to other actively growing sites such as the lower pods, which serve as strong sink. In spite of large genotypic variation, photosynthetic rate is hardly exploited for yield improvement in chickpea. Complex nature and its strong interaction with environment make it difficult to manipulate the process of photosynthesis. In most of the cases, photosynthetic rate is highly unstable due to environmental factors and hence, it is poorly correlated with crop productivity. Therefore, in most of the  $C_3$  crops including chickpea, net assimilatory surface or total leaf area available for maximum interception of solar energy and carbohydrate reserves in stem, pods and leaves are suggested to be the important yield determining factors rather than photosynthetic rate at any given time. However, Bhattacharya and Singh (1999) reported a strong correlation between seed yield and photosynthetic efficiency during flowering and 10 days after flowering under normal as well as late sown conditions.

## Nitrogen Fixation

Chickpea leaves are able to assimilate nitrate through the activity of enzyme nitrate reductase. This is usual mode of nitrogen fixation similar to large number of crop species *via* nitrate uptake from soil entering into the roots and subsequently reduces to ammonia and other products of nitrogen assimilation pathway. However, chickpea accumulates a great proportion of nitrogen during the period of its growth and development by fixing atmospheric nitrogen in the root nodules having symbiotic association with *Rhizobium*. These nodules are the primary sites of nitrogen fixation supplementing the nitrogen requirement of crop.

Generally, nodule formation and nitrogen fixation rates increase from vegetative phase to reproductive phase with a peak often observed at early



pod initiation (Khanna-Chopra and Vidya 1987). During rapid pod filling phase, the nitrogen demand for sink (seed) growth increases tremendously. As a result, bulk of the nitrogen is mobilized to growing sinks. Often ribulose-1, 5-bisphosphate carboxylase oxygenase (RuBISCO), a major soluble enzyme of photosynthetic pathway in the leaves is subjected to degradation. The RuBISCO after degradation produces nitrogenous products which act as the alternate source of nitrogen during pod development. Due to disintegration of RuBISCO the photosynthetic rates of subtending leaves to pod decline drastically. Such leaves undergo forced senescence and abscission (Grover *et al.*, 1985). This kind of induced maturity is observed in chickpea.

Hardy *et al.* (1977) opined that nitrogen fixation is possibly the major limiting factor in chickpea productivity. Sinha *et al.* (1983) showed that in addition to accumulation of nitrogen, inefficient mobilization of accumulated nitrogenous substances to seeds could be equally important factor limiting the seed yield. They observed that only 21-49% reserve nitrogen was mobilized to the developing sinks and rest remained unused in the vegetative parts. Thus, there is a tremendous scope to improve nitrogen mobilization efficiency by selecting appropriate plant type.

### Partitioning of Carbon and Nitrogen

Besides transport of currently synthesized photosynthates and nitrogen (N) to the developing seeds, pre-anthesis stored reserves of C and N are reported to be an important assimilate source for seed filling, particularly when plants are subjected to water deficit. Generally in pulses, 2-42% of seed dry matter has been reported to be contributed by remobilization from vegetative tissue (Bushby and Lawn, 1992). In chickpea, a decrease in dry matter of stems, leaves and pod walls of field grown plants suggest that dry matter (C, N and others) is important as an alternative assimilate source to current photosynthates (Leport *et al.*, 1999). It was estimated that one-third of the pod dry matter is derived from the remobilization of dry matter from vegetative tissues in chickpea (Khanna-Chopra and Sinha, 1982). The studies conducted by Davies *et al.* (2000) showed that carbon and nitrogen assimilated prior to podding can supplement to the filling seeds in both well-watered and water-stressed conditions in chickpea. Thus, remobilization of pre-podding N is an essential source of nitrogen for seed filling irrespective of the prevailing environmental conditions.

### Physiology of Developing Grains

Chickpea seeds are rich in protein and as compared to cereals, the seed protein content ranges from 20 to 25% of the dry weight depending upon the variety and the environmental condition. Unlike cereals, the carbohydrate content in chickpea seeds is about 68% of the dry weight, whereas lipid and ash contents are 5% and 4%, respectively. The seed size



of chickpea, as assessed by 100-seed weight, varies between 12 and 30 g for *desi* types, while that of *kabuli* type is much higher. The seed size is one of the most stable characters, which is less influenced by environmental conditions. During rapid pod filling stage, the seeds become the major sink of the plant having high demand of both carbon and nitrogen. Spray of potassium iodide on crop during reproductive growth is one of the methods to assess the contribution of reserve materials stored in vegetative parts to the development of grains. Potassium iodide simulates leaf senescence in a similar manner as caused by drought (Nicolas and Turner, 1993). This leads to redistribution of dry matter stored in vegetative parts, such as in stem and leaves, to the sink. This ability of cultivars to reallocate assimilate may also be a function of the strength of the sink for assimilates. Various studies suggest that redistribution of dry matter from stem and leaves can provide up to 60% of the final seed weight in chickpea (Leport *et al.*, 1999) and that the pod wall can contribute about 9-15% of the final seed weight under terminal drought (Davies *et al.*, 1999). Mohapatra *et al.* (1997) have suggested that sucrose synthase may be a measure of sink strength in chickpea. Recent studies show genotypic variation for sucrose synthase activity, and it has been correlated with seed size (ACIAR-ICAR unpublished results).

Studies using  $^{13}\text{C}$  showed that less than 20% of the seed carbon comes from pre- podding stored assimilates when chickpea plants were water-stressed (Davies *et al.*, 2000). Other studies using  $^{14}\text{CO}_2$  suggested that the leaves, particularly those subtending the pods, are the primary source of carbon for seed growth, (Singh and Pandey, 1980). Previous studies have shown that during the early stages of seed development, pod wall of chickpea can fix  $\text{CO}_2$  under well-irrigated condition, but causes significant losses of  $\text{CO}_2$  through respiration in the dark (Sheoran *et al.*, 1987). Studies on other legumes indicate re-fixing of respired  $\text{CO}_2$  inside the pod and its use by the growing seeds. It is, therefore, suggested that this recycling of seed respired carbon by fruit walls may be an important mechanism for reducing carbon losses. This phenomenon is known as recycling of  $\text{CO}_2$  inside the pod. Ma *et al.* (2001) reported that when water-stress suppresses the  $\text{CO}_2$  fixation rate in leaves and pods during seed filling, higher rates of  $\text{CO}_2$  recycling inside the pods help to compensate for the low rates of photosynthesis in the leaves and provide an important source of carbon redistribution from pod walls, leaves and stems in water-stressed chickpea (Davies, 2000).

Recent studies suggest that seed filling process is less affected by water stress as compared to whole plant, *e.g.* stem, leaves and pod walls. A change of turgor potential from 0.25 to 0.97 MPa occurred in stems and pod walls when stressed plants were watered. However, rehydration did not alter the turgor potential of seed coat cells and it remained almost unchanged at 0.1 to 0.13 MPa. It is generally agreed that the developing embryo inside the seed has no direct symplastic connection to the



surrounding parental tissues, and water, carbon and other nutrients must pass through the apoplast to reach the embryo (Bradford, 2004). In chickpea, the seed as a whole is isolated from the parent plant by a barrier to water exchange located between the pod wall and the seed coat. The study suggests that both water and nutrients enter the seeds via the phloem (Pate *et al.*, 1985). Shackel and Turner (2000) successfully demonstrated that seeds of chickpea can be isolated from pod water status. Therefore, the turgor in the seed coat remains relatively constant despite changes in the water potential of its surrounding environment. This homeostasis may be a part of a mechanism to ensure continued seed filling and assimilate redistribution even when low water potentials have reduced the current availability of assimilates from the leaves.

### Drought Tolerance

Among various abiotic stresses, drought plays a very important role and it drastically reduces the yield up to 30%. Under severe drought condition the yield losses may be as high as 75%. Since drought is recurring condition of abnormally dry weather leading to moisture stress for plants, its severity depends on a number of factors, including the extent of moisture deficiency, its duration and spatial spread. It can be aggravated by mismanagement of land and water resources. Drought occurrence is unpredictable, therefore, screening of genotypes under such variable condition may not be very reliable, hence it is suggested that an molecular technique may be used to identify and developed drought resistant chickpea genotypes.

During drought, the concentration of solutes inside the plant cells rises and, therefore, water potential of plant cells drops. This in turn destabilizes the cellular membrane and disrupts photosynthesis. In fact, under severe drought the photosynthetic rate of the plant may drop to such a low level that it is unable to synthesize enough photosynthates to sustain its energy (ATP) requirement to maintain even regular metabolism, and eventually dies. However, when photosynthesis slows or stops, the chloroplasts of the cells continue to be in excited state, resulting in the synthesis of reactive oxygen species (ROS) such as super-oxides and peroxides. ROS are very potent agents to damage the cell membrane and cellular enzymes.

In chickpea attempts have been made to identify drought tolerant genotypes by various methods, viz. based on germination tests under restricted moisture supply (Saxena *et al.*, 1983) or under low osmotic potential, and on the basis of drought index, i. e., yield reductions under water stress conditions as compared to that under irrigated condition. Development of pod is generally considered most sensitive to water stress. The magnitude of drought resistance varies from seedling to reproductive stage. So, determination of productivity potential in relation to water availability at various stages is a good approach to identify drought resistant genotype.



Plants have developed a number of strategies to resist drought. These falls into three broad categories: drought escape, dehydration postponement and drought tolerance. In general, drought escape refers to the growth patterns that plants have developed throughout evolution to reduce their exposure to environmental stresses. However, short growth duration (generally defined by early flowering or early phenology) constitutes an important attribute of drought escape, especially under terminal drought conditions. In legumes it involves identification of plant with early flowering and pod initiation, rapid but short growth periods with matching phenology (flowering, podding and maturity) to the available soil moisture (Turner and Whan, 1995; Siddique *et al.*, 1997). Genotypic variations in different components, *viz.* early vigour, faster canopy development, days to flowering, podding, seed filling and maturity is reported in chickpea (Kumar *et al.*, 1999). In environments where terminal drought is likely to occur, selection for early flowering has been highly successful (Subbarao *et al.*, 1995a; Siddique *et al.*, 1999), however, selection for early flowering may not be helpful in increasing yields in areas with high risk of frost damage at flowering, as extremely low temperature causes poor fertilization (Srinivasan *et al.*, 1998).

Dehydration postponement refers to the strategies adopted by plants to maintain high water potential during periods of water deficit. Plants naturally transpire, and lose a significant amount of water via this route. Water deficit causes the guard cells of the stomata to lose their turgor. This closes the stomata and significantly reduces the rate of transpiration. Water deficit inhibits growth in the plant because cell turgor is required for cellular proliferation. In many plants, leaves roll up during dry weather. All of these strategies protect plants against water loss, but they also diminish photosynthesis, and are, therefore, detrimental to plant's survival over long period of stress. The pattern of root growth also changes in response to water availability, particularly during late pod fill stage (Panwar, 2006). Higher degree of proliferation in the root system enables the plant to survive during dry spells.

The stomatal apparatus plays a key role in regulating the water loss through exposed surface of the plants. Plant surface structure, form and composition carry a major impact on the plant interaction with the environment. Plant surface absorbs solar energy, and a part of it is used for photosynthesis and the maximum fraction is dissipated by reflection, emission and in the form of latent energy by transpiration. Plant surface (shoot) structure determines the reflective properties of the leaves and resistance exerted to transpiration. Leaf resistance to transpiration is largely determined by stomatal activity. Hydration state of leaves and humidity of air are considered to have major influence on the conductance (reciprocal of resistance) of stomata in the field grown chickpea (Turner, 1991). Differences in stomatal conductance in response to the leaf water potential have been observed in grain legumes (Lawn 1982; Flower and



Ludlow, 1987). Genotypic differences in stomatal responses can be assessed by using porometry, but this is a slow and tedious method, and only limited number of genotypes can be screened (Leport *et al.*, 1999). Techniques are now available to measure canopy temperature by infrared thermometry for screening chickpea germplasm with varying responses to drought.

### Root Depth and Length Density

The most important control of plant water status is associated with the root. Roots are the main engine for meeting transpirational demand. Two major dimensions of root, i.e., root depth and root-length density, are the major characteristics determining water availability to plant from soil. The more practically important dimension is root depth, which enables plants to extract soil moisture from deeper soil layers. It is a primary component of drought resistance. The development of lateral roots at very shallow soil depth has a role in capturing small amount of intermittent rainfall. Various experiments conducted at Indian Institute of Pulse Research, Kanpur, under rain out shelter and the dug out plots revealed the genotypic variations in rooting pattern. Such studies enable the researchers to adopt a screening technique where the crop can be raised under simulated soil moisture condition. Besides root depth and root-length density some other characteristics of root, viz. its morphology, hydraulic conductance, and function are equally important to meet the transpirational demands of the shoot (Passioura, 1982). Therefore, it is obvious that for maximizing extraction of soil moisture by plants, the requirements are (1) deep penetration of roots; (2) adequate root density and (3) adequate longitudinal hydraulic conductance in roots (Fischer *et al.*, 1982). The water uptake pattern across the depth of rooting zone is not uniform. In general, nearly 40% of the total water uptake by roots occurs over the first one fourth of rooting zone, 30% from the second, 20% from the third, and 10% from the last one fourth of the total rooting depth (Doorenbos and Pruitt, 1975; Nageshwara Rao and Wright, 1994). Crop plants often maintain higher root length densities than required in the surface layer to facilitate rapid uptake of current rain before it evaporates, to provide reserve capacity in case of disease and pest damage, to extract relatively immobile nutrients like phosphorous and calcium, and to compete with weeds or other neighbouring plants for both water and nutrients (Passioura, 1983). Depending upon the target environments, certain root traits may be more important than others and, therefore, genetic improvement will depend upon the type of traits required relative to those present in current cultivars.

A wide genotypic variability among root characters, such as density and depth, and total root biomass, has been reported in chickpea. Krishnamurthy *et al.*, (1996) identified chickpea genotypes with drought tolerance through increased root biomass. A drought resistant genotype



ICC 4958 has 30% higher root dry matter than the standard known cultivar Annigeri. Cultivar Annigeri is found to be relatively more sensitive to drought stress. Efforts are underway to combine this root trait with adaptive and high yielding traits of Annigeri. A number of lines with ICC 4958 root phenotype and Annigeri shoot phenotype have been tested and some of them have shown higher yielding ability in drought environments (Legume Program, 1992).

Genotypic variation in rooting length, density, morphology, dry matter, branching pattern and dynamics were studied at Indian Institute of Pulses Research, Kanpur, using 16 genotypes (Basu and Singh, 2003). Highly significant differences for root traits were observed among genotypes. At 60 DAS (days after sowing), roots of genotypes BG 256, ICC 4958, BG 364, K 850, ICCV 92944 and IPC 94-37 showed extensive lateral branching at 30-60 cm soil depth. Root dry matter per plant was highest in genotype ICC 4958 (320 mg) followed by genotypes K 850, BG 364, BG 256 and ICC 94-132. On the other hand, root dry matter in genotypes Annegiri, ICCV 10 and C 214 was within the range of 100-140 mg plant<sup>-1</sup>. Total root length, including main and lateral, was highest in genotype BG 364 followed by in genotypes ICC 4958, K850, BG 256, IPC 94-132, Annegiri, ICCV10 and C 214. Interestingly genotypes BG 256, BG 364 and IPC 94-37 showed high yield at 7 different locations (Anonymous, 2000). Thus, it indicates that well developed root system may contribute towards higher yield. Genotypes ICC 4958, K 850 and ICCV 92944, already known as drought tolerant genotypes because of profuse rooting system, showed relatively higher yield as compared to other genotypes at different locations.

### Osmotic Adjustment

Osmotic adjustment is the process of active accumulation of solutes in plants in response to increased water deficits. Osmotic adjustment helps in maintaining turgor or reducing the rate of turgor loss with decrease of water potential (Turner and Jones, 1980). Osmotic adjustment has been shown to maintain stomatal conductance and photosynthesis at low water potential, delays leaf senescence and death (Hsiao *et al.*, 1984), reduces flower abortion, and improves root growth and water extraction from the soil as water deficit develops (Morgan and King, 1984).

When water deficit develop, various solutes accumulate in cells and subsequently tissue osmotic potential is reduced. Tissue osmotic potential can be reduced merely by the concentration of cellular solution due to water loss. Osmotic adjustment is derived from the net increase in cellular osmolality caused by the active accumulation of solutes such as various ions (mainly potassium), sugars, polyols (e.g. fructans), and organic acids [amino acids (e.g. proline), glycinebetaine] etc. Osmotically active, low- molecular mass compounds are called as osmolytes (Bajaj *et al.*, 1999), Osmolytes like glycine betaine, proline,

and sugars such as mannitol, can act as a scavenger of hydroxyl radicals *in vitro*. Osmolyte like trehalose confers high tolerance to dehydration; fructans, and D-ononitol (1-D-4-O-Methyl-myo-inositol), allow the osmotic balancing of Na<sup>+</sup>. Osmotic adjustment occurs when cellular water deficit exceeds a certain threshold level, which is not universally determined. Nor has the exact signaling of osmotic adjustment has been resolved. Osmotic adjustment is a slow process requiring time, and very rapid desiccation in experiments or even in the field may not allow osmotic adjustment. Typically the rate of desiccation should be greater than 0.1 MPa day<sup>-1</sup>. Practically it should take about 2-3 weeks from fully hydrated state to wilting for the expression of osmotic adjustment in whole plant. In crop plants, the rate of osmotic adjustment varies greatly among species and cultivars (Blum, 1996).

Osmotic adjustment has been shown to benefit plants in survival of and recovery from short dry periods (Meyer and Boyer, 1981). Osmotic adjustment and low osmotic potential are considered compatible with growth and yield, as they aid in the maintenance of leaf turgor.

Osmotic adjustment is probably one of the most crucial components of adaptation to drought stress. Besides its role in turgor maintenance, the accumulated solutes protect cellular proteins, various enzymes, cellular organelles, and cellular membranes against desiccation injury. Hence, cell and tissues continue to function despite the progressing desiccation. One consequence of osmotic adjustment at the whole plant level is the continued growth of roots and the extraction of moisture from deeper soil layers. Finally, osmotic adjustment is crucial for the conservation of meristem viability under desiccation and again fast recovery of function upon rehydration. Upon rehydration the various organic osmolytes are recycled and metabolized, therefore, considered as an important energy resource for recovery of growth (Blum *et al.*, 1999).

Osmotic adjustment in different cultivars of various pulses and peanuts has been estimated by Blum *et al.*, 1999, and shown in Table 3.

**Table 3.** Variation in osmotic adjustment in some legumes species

Species	Organ	Range in osmotic adjustment (-MPa)
Soybean	Leaf	0.3 to 1.0
Pigeonpea	Leaf	0.1 to 1.3
Cowpea	Leaf	0.1 to 0.5
Mungbean	Leaf	0.2 to 0.4
Peanut	Leaf	0.3 to 1.6
Chickpea	Leaf	0.0 to 0.5

Source: Blum *et al.*, 1999

The capacity of osmotic adjustment observed for various grain legumes is modest except in pigeonpea and peanut. However, the osmotic adjustment



has been shown to be correlated with yield under dry land conditions in chickpea (Morgan *et al.*, 1991). Osmotic adjustment was not found to delay the reduction in photosynthesis in grain legumes (Leport *et al.*, 1999), but has been observed to delay leaf senescence and increase the mobilization of reserves in some grain legumes (Flower and Ludlow, 1986). Significantly greater seed yield in groups of genotypes with high osmotic adjustment than in groups with low osmotic adjustment has also been reported under water deficit condition in various crops (Morgan, 1983; 1995; Ludlow *et al.*, 1990). The investigation was conducted on chickpea cultivars differing in osmotic adjustment capacity (Lecoeur *et al.*, 1992; Moinnuddin and Chopra, 2004). It was evaluated whether an osmotic adjustment based mechanism is responsible for sustained crop productivity under water deficit. As compared with low osmotic adjustment cultivars, high osmotic adjustment cultivars generally showed an improved plant water status. High osmotic adjustment cultivars proved significantly superior to low osmotic adjustment ones in seed yield and most of its parameters. The yield benefit was 26% and 48% at moderate and severe moisture stress levels. However, Turner *et al.* (2007) could not get any advantage of osmotic adjustment in yield improvement in chickpea under terminal drought.

Little work on chickpea has been done on this aspect (Morgan *et al.*, 1991; Leport *et al.*, 1999), although chickpea is an important crop with a higher osmotic adjustment capacity than several other legume crops (Leport *et al.*, 1999). It needs to be determined whether osmotic adjustment can be used as a selection criterion for screening drought resistant cultivars for rain-fed areas, which cover approximately 70% of the total agricultural land in India. Osmotic adjustment has been reported in field-grown chickpea cultivars also.

Serraj and Sinclair (2002) emphasized that osmotic adjustment has more significance for root growth rather than any definite relation with grain yield. Recent studies show genotypic variation for osmotic adjustment in chickpea. Trial conducted at IIPR, Kanpur, with 16 chickpea genotypes grown at different soil moisture regimes revealed that osmotic adjustment is significantly correlated to grain yield (Basu and Singh, 2003). Genotype K 850, when subjected to one level of moisture regime to another, showed maximum variation in osmotic potential, indicating the extent of flexibility in osmotic potentials.

### Dehydration Tolerance

The ability of cells to continue metabolizing at low water status is termed as dehydration tolerance. The last line of defense that a plant has against water deficit is dehydration tolerant protoplasm (Turner and Jones, 1980). Plants that are exposed to severe drought use dehydration tolerance mechanisms. Such plants are able to survive under low water potentials by several characteristics, including lowering their osmotic potential (i.e., active solute accumulation), or by protoplasmic

resistance. Dehydration results in irreversible disruption of cellular organization and metabolism. In certain situations, such as extended periods of drought, plants cannot avoid a decrease in water potential. Some of the parameters associated with drought resistance characteristics and yield components, and their relative easiness of quantification to identify drought resistance and susceptible genotypes linked with their yield potential are given in Table 4.

**Table 4.** Usefulness for yield improvement and ease of screening for drought resistance characteristics and yield component characteristics in breeding programs of crop plants under drought

Drought resistance characteristic			Yield component characteristic		
Characteristic	Usefulness	Ease of screening	Characteristic	Usefulness	Ease of screening
Drought escape			Increased transpiration		
Phenology	Very high	Easy	Early vigor	Variable	Easy
Developmental plasticity	High	Easy	Root density and depth	High	Very difficult
Dehydration Postponement			Transpiration Efficiency		
Stomatal control	High	Difficult	Conventional Methodology	High	Very difficult
Absciscic acid accumulation	Questionable	Difficult	Carbon isotope discrimination	High	Easy
Osmotic adjustment	High	Difficult			
Root density and depth	High	Very Difficult			
Dehydration Tolerance			Harvest Index		
Membrane stability	Low	Easy	Assimilate Redistribution	High	Easy
Lethal water potential	Medium	Difficult			
Proline accumulation	Questionable	Easy			

Source: Turner *et al.*, 2001

Most crop plants belong to dehydration-intolerant category; in general, plants with poorly developed drought avoiding mechanisms have the greatest dehydration tolerance (Bewley, 1979). Sinclair and Ludlow (1986) considered relative water content as a most meaningful index for identifying legumes with contrasting differences in dehydration tolerance. In environments where water deficits can occur at any stage of growth, dehydration tolerance may have some role in survival of the crop until soil moisture levels improve with succeeding rains (Turner, 1979).



## Membrane Stability

Membrane stability is often measured by measuring the leakage of solutes from the cells. Drought tolerance mechanism involves stability of membrane, which could be assessed through electrolyte leakage from desiccated tissue. Cell-membrane stability (CMS) is considered to be one of the major selection indices of drought tolerance in cereals (Zhang *et al.*, 2000). A major impact of plant environmental stress is cellular membrane modification, which results in its perturbed function or total dysfunction. The exact structural and functional modification caused by stress is not fully understood. However, the cellular membrane dysfunction due to stress is well expressed in increased permeability and leakage of ions, which can be readily measured by the efflux of electrolytes. The estimation of membrane dysfunction under stress by measuring cellular electrolyte leakage from affected leaf tissue into an aqueous medium has been used for measuring CMS and for screening stress resistance. Electrolyte leakage has been used as a screening technique for heat and dehydration tolerance. Srinivasan *et al.* (1996) found genetic variation for heat tolerance in chickpea by testing membrane stability and photosystem II function in leaves at high temperature. In chickpea, 40-50% of the terminal flowers abort in some varieties due to the high temperatures near the end of flowering. Thus a large part of the reproductive phase, both early and late, is exposed to cold and high temperatures, respectively, reducing seed yields up to 50% (Dua, *et al.*, 2001). Membrane stability index, as a trait, has been suggested a suitable parameter for screening large number of crop genotypes for resistance to stress (Singh, *et al.*, 1992; Deshmukh *et al.*, 1996; Gupta and Namdeo, 1996; Deshmukh *et al.*, 2004a; 2004b). Better membrane stability and low specific leaf area may help a genotype in maintaining more filled pods and higher grain yield under stress conditions in chickpea (Gupta and Panwar, 2006).

A minimum of 28 to 30% of water is required in plant cells for the maintenance of functional integrity of membrane structure (Blum, 1988). If plants cannot maintain this level of water in the cells through dehydration avoidance strategies, membrane disorders may occur due to lipid peroxidation or structural changes that are largely physicochemical (Blum, 1988). This is because any damage to membrane's structure can prove detrimental for plants cell functioning and ultimately to the survival of plants. Tolerance to dehydration apparently depends on the ability of the cells to maintain integrity of the cell membranes and prevent denaturation of proteins (Gaff, 1980). Compatible solutes such as sugars, amino acids, such as proline, and quaternary ammonium compounds (glycine betaine) protect the membranes and enzymes from dehydration induced damage (Hsiao *et al.*, 1984; Schwab and Heber, 1984). Maintenance of nuclear integrity is essential for dehydration tolerance implying that survival of severe dehydration requires that the cell repairs or reconstructs outside the



nucleus. Substantial genotypic variation for heat tolerance was found in all legumes. However, the relationship between electrolyte leakage from desiccated leaf discs and crop performance under water-limited conditions has not been demonstrated.

Interest has been growing in the possible involvement of polyamines (PAs) in the defense reaction of plants to various environmental stresses (Kao, 1997; Kakkar and Sawhney, 2003). PAs are polycationic cellular molecules that play an essential role in cell growth and differentiation. Interactions of PAs with membrane phospholipids may stabilize the membranes under conditions of stress (Roberts *et al.*, 1986). It has been found that stress-tolerant plants increase their endogenous PAs levels to a much greater extent than sensitive ones (Lee, 1997). Furthermore, transgenic plants overproducing PAs possess greater stress tolerance (Galston *et al.*, 1997), and exogenous PAs confer protection from a variety of abiotic stresses (Nayyar and Chander, 2004). Tests have been carried out for variation in water stress sensitivity between chickpea and soybean plants related to changes in the levels and functioning of endogenous PAs. Finding showed that chickpea seedlings experienced considerably less water stress injury to its membranes, as determined by electrolyte leakage, and to growth compared to soybean (Nayyar *et al.*, 2005). These differential responses could be related to significantly more endogenous PAs in chickpea than in soybean, as high PAs accumulation has been related to acquisition of stress tolerance (Lazcano-Ferrat and Lovatt, 1999). Chickpea seedlings might support a higher content of PAs during water stress due to their better capacity to maintain turgor. Alternatively, it is possible that accumulation of PAs itself affects the osmoregulation and thus contributes towards improved water status. In a related study, Nayyar *et al.* (2005), found chickpea to accumulate more osmolytes like proline and glycine betaine than soybean during similar conditions of water stress, which might explain its superior water content.

### Transpiration Efficiency and Water-Use Efficiency

Transpiration efficiency (TE) is defined as aerial dry matter produced per unit of water transpired by the crop. Transpiration efficiency (g biomass produced  $\text{kg}^{-1}$  of water transpired) is an important characteristic to improve crop productivity, especially under limited water condition.

It is given that yield is proportional to crop water-use. Crops must use water under stress in order to sustain yield. Drought resistance is a finite trait. Life cannot be sustained without water. Yield of crops under water-limited conditions also depends on water used for biomass production, and is a product of transpiration and crop water-use efficiency.

Water-use efficiency (WUE) for yield is often defined as a ratio between economic yield to total evapotranspiration, and equated in a simplified manner with drought resistance. The large accumulation of knowledge on crop WUE as derived from research on carbon isotope



discrimination allows some conclusions on the relations between WUE on the one hand, and drought resistance and yield potential (YP) on the other hand (Blum, 2005). Improved WUE on the basis of reduced water-use is expressed in improved yield under water-limited conditions only when if there is need to balance crop water-use against limited and known soil moisture.

The carbon isotope discrimination method is advocated to estimate the water-use efficiency of the crop under field condition. A high TE is obtained when the  $\text{CO}_2$  concentration in the stomatal chamber is maintained at low levels, which happens when the photosynthetic activity is high, or when the conductance of stomata is low. Enzymes involved in photosynthesis discriminate  $^{12}\text{CO}_2$  against its stable isotope  $^{13}\text{CO}_2$ . However, under conditions of high photosynthetic activity or low stomatal conductance, a different proportion of  $^{13}\text{CO}_2$  is used in the photosynthetic process. Therefore, the differences in the proportion of  $^{13}\text{C}$  in the biomass can be used to indirectly estimate TE. Lower  $^{13}\text{C}$  discrimination is associated with higher TE (Subbarao *et al.*, 1995b). However, contradictory reports are also there (Condon *et al.*, 1987). This carbon isotope discrimination method has been applied in several crops, particularly grain legumes, to estimate the TE. A breeding program for high TE groundnut varieties is ongoing, and preliminary evidence shows that genotypic variations exist for TE in chickpea. Yield of water-limited crops is determined by crop water-use and by plant water-use efficiency, each of which will be affected by the anticipated rise in atmospheric carbon dioxide ( $\text{CO}_2$ ) concentration and concomitant increase in temperature. At the leaf level, a given proportional increase in  $\text{CO}_2$  concentration generally elicits a similar (relative increase in transpiration efficiency) ratio of net photosynthesis to transpiration (Polley, 2002). For crops, it is yield of the economically important product, rather than total biomass that is of interest.

Crop yield can be improved considerably by reducing evaporation and other nonproductive losses of water (Turner, 1993). Evaporative losses have been estimated to be between 10% and 50% of total water loss in cropped systems (Fischer and Turner, 1978). Higher yield per unit rainfall is one of the most important challenges to achieve in dry land agriculture. Improving water-use efficiency may be one means of achieving this goal.

Studies were conducted at ICRISAT, Patancheru, Hyderabad taking ten chickpea genotypes (Annigeri, ICC 10448, ICC 13219, ICC 14199, ICC 1882, ICC 283, ICC 4958, ICC 5337, ICC 5680 and ICC 8261) with contrasting growth durations, types (*desi* or *kabuli*), growth habits, and root systems. Variance and its significance for water schemes, genotypes, and their interaction for carbon isotope discrimination ( $\Delta^{13}\text{CO}_2$ ), and transpiration efficiency under well watered and drought stress conditions were studied. Significant differences in  $^{13}\text{CO}_2$  discrimination of these genotypes were observed. The  $^{13}\text{CO}_2$  in stressed



plants was significantly higher than that in the well-watered plants. Genotype ICC 5337 showed the highest  $^{13}\text{CO}_2$  discrimination (-26.0‰) as well as highest TE under stress condition. Genotype ICC 4958, a well-known drought resistant variety, had a superior  $^{13}\text{CO}_2$  value than the other genotypes under stress conditions. The TE under stress was significantly higher than TE under well-watered condition. A significant positive correlation between  $^{13}\text{CO}_2$  and TE was observed under the stress condition ( $r = 0.857^{**}$ ). This result shows that TE of chickpea grown under drought conditions could be estimated through  $\Delta^{13}\text{CO}_2$  measurement (Kashiwagi *et al.*, 2006).

Water-use efficiency (WUE) in plants is affected by a number of factors. Elevated atmospheric  $\text{CO}_2$  causes a reduction in stomatal conductance and transpiration rate, but photosynthetic enhancement (Polley, 2002). Increase in air temperature may increase the rate of transpiration by increasing the vapour pressure deficit (VPD) of the air and leaf, thus resulting in an increase in vapour pressure gradient between leaf and atmosphere, and this may offset the effect of elevated  $\text{CO}_2$  mediated stomatal closure causing reduced transpiration. The stomatal conductance and canopy boundary layer conductance regulate the process of transpiration. Impact of high temperature and atmospheric conductance on water-use efficiency has been reviewed by Polley (2002), and he suggested that increase in  $\text{CO}_2$  concentration will not be in proportion with the increase in WUE, but it will be less because of the simultaneous increase in leaf temperature and vapour pressure deficit between the leaf and air.

Interaction effects of high  $\text{CO}_2$  and temperature on soybean crop revealed that the extent of reduction in evapo-transpiration by elevated  $\text{CO}_2$  was offset by elevated temperature and the benefits of improved water-use efficiency (WUE) at high  $\text{CO}_2$  are eroded by the decrease in harvest index due to high temperature. If the globe air temperature rises along with atmospheric  $\text{CO}_2$ , the crop water-use may increase particularly in arid and sub-tropical and tropical region.

### Stem Reserve Mobilization

Remobilization of starch in stems contributes to grain yield of legumes. Seed growth in legumes is partially supported by translocated plant reserves (Meckel *et al.*, 1984; Wright *et al.*, 1991). These reserves are mainly non-structural carbohydrates which can be mobilized for various plant needs under moisture deficit, which is particularly necessary if current assimilation cannot meet plant requirement (Ludlow and Muchow, 1990). These carbohydrates reserves act as a buffer against availability of current photosynthates, particularly during seed filling under stress (Schnyder, 1993), because moisture deficit affects translocation lesser than that to the photosynthesis and respiration (Boyer, 1976). The ability to store and remobilize large quantities of carbohydrates for osmotic adjustment, or for grain filling under terminal drought, improves the ability of the cultivar to perform better under



drought (Bidinger *et al.*, 1977; Blum *et al.*, 1983). Remobilization of stored reserves can influence the performance of a genotype in both intermittent and terminal moisture deficit environments. In intermittent moisture deficit situations, stored carbohydrates determine the ability to recover from stress (Sheldrake and Narayanan, 1979). Therefore, usage of stem reserves depends on the available storage, and the rate and duration of mobilization of storage materials to the grains. The size of the storage strongly depends on growing conditions before anthesis and the genotype. Under conditions of terminal moisture deficit, net photosynthesis decreases (Berry, 1975), thus the proportion of translocation of stored soluble carbohydrate for grain filling becomes larger, although in absolute terms it is essentially the same, (Austin *et al.*, 1977; Bidinger *et al.*, 1977; Fischer, 1979).

A significant positive relationship has been reported between the rate of stem dry matter loss after anthesis and grain production capacity under conditions of moisture deficits across a range of genetic materials (Rawson *et al.*, 1977).

In chickpea, nearly 15 to 20% of the total seed weight is derived from remobilization of stored carbohydrates (Saxena, 1984). Stem reserves mobilization or the percentage of stem reserves in total grain mass is affected by sink size, by the environment and by cultivar. In certain cases the use of 2% urea or diammonium phosphate as foliar spray has given the beneficial result under the rainfed/water stressed condition, as it maintains the N level of the leaves and availability of current photosynthesis by maintaining the leaf area and RuBISCO activity.

### Symbiotic Nitrogen Fixation

Chickpea meets 80% of its nitrogen requirement from symbiotic nitrogen fixation and can fix up to 140 kg N ha<sup>-1</sup> from air during its growth period. It leaves substantial amount of residual nitrogen behind for subsequent crops and adds much needed organic matter to maintain and improve soil health, long-term fertility and sustainability of the ecosystems.

Thovaragah and Ball (2006) worked on the nitrogen fixation and amino acid, and ureide association in chickpea. The metabolic products of nitrogen fixation (N<sub>2</sub>) in a legume are either amides (asparagine, glutamine) or ureides (allantoin and allantoic acid). Ureides are synthesized solely in the nodules. In chickpea; however, the exact metabolic products resulting from N<sub>2</sub> fixation are not known. Therefore, chickpea is classified as both an amide and ureide exporter, on the basis of the concentration of both types of N-products found in the shoot.

Nodulation, nitrogen fixation, environmental and plant factors affecting N<sub>2</sub>-fixing ability in legumes, in general, is discussed in Chapter 4.

### Strategies for Crop Improvement Under Drought

Drought stress is a complex syndrome, involving several atmospheric, edaphic and agronomic factors, and is characterized by three major varying parameters, i.e. timing of occurrence, duration, and intensity. The high variability in the nature of drought and the insufficient understanding of its complexity have made it generally difficult to characterize the physiological traits required for improved crop performance under drought, consequently limiting plant breeding efforts to enhance the drought tolerance of crops.

The assessment of the moisture-availability pattern of the target environment is critical for developing genotypes adapted to target environments, and to identify environments with similar drought patterns. Characterizing drought in post-rainy season crops, such as chickpea, is simpler, compared with the intermittent drought experienced by rainy season crops. This is because much of the rainfall is received before the planting of the crop, which is, therefore, grown almost entirely on stored soil moisture and exposed mostly to progressively increasing (terminal) water deficits (Serraj *et al.*, 2002). In order to identify sources of drought tolerance, it is necessary to develop screening methods that are simple and reproducible under the target environmental conditions. Therefore, managing drought-screening nurseries requires a careful analysis of likely sources of non-genetic variation among plots, replications and repeated experiments and establishment of procedures for minimizing these factors (Bidinger *et al.*, 2000).

### Effect of Low Temperature on Pod Set and Yield

The three major factor affecting chickpea growth and reproduction are temperature, day length and available soil water. Unlike other winter growing crops chickpea are very susceptible to cold conditions especially at flowering. As a general rule the first chickpea flower is found around the eighth node of the main stem. However, experiments have shown that it is the average daily temperature ( $\text{max.} + \text{min.})/2$  that is critical for flowering and pod set, rather than any specific effect of maximum or minimum temperatures. The critical mean, or average daily temperature, for abortion of flowers in most of the current varieties is below 15°C. Abortion occurs below this temperature because the pollen becomes sterile and reproductive structures do not develop. Flowers may develop below this temperature (pseudo flowers), but they contain infertile pollens. Once the flowers are produced a period of cool weather can cause flower or bud abortion to varying degrees. If flowering starts before average daily temperature reaches to 15°C, then flowers will continue until temperature increases beyond this critical temperature. The best record are those collected in the crop canopy-as compared to temperature profile recorded at air meteorological department.



It is also reported that planting time is quite crucial as planting at optimum time maximum water-use efficiency (WUE) and yield, and can minimize frost damage. Early planting can lead to excessive biomass production, reduced water-use efficiency and increased frost damage.

Sandhu and Arasakesery (2003) working on 57 *desi* genotypes of chickpea under Punjab condition in India, revealed the genotypic tolerance to cold temperature at 5°C and 10°C. Genotypes ICCVs 88501, 88502 and 88503 had more number of productive pods at 5°C than at 10°C and also flowered early as compared to other cultivars. It is clearly indicated that in chickpea pollen viability is severely affected by low temperature. The genotypes ICC 3197, ICC 72419, ICCV 88501 and ICCV 88502 are reported to be promising for cold tolerance. The pollen viability of above genotypes was studied in the flowers exposed to at least for three days of minimum temperatures (Srinivasan *et al.*, 1999). Siddique and Sedgley (1986) reported that at low temperature, pollen tube grow slowly, fertilization is less likely and flowers often abort. Rate of pollen tube growth at low temperature is closely related to cold tolerance. At ICARDA and ICRISAT have identified genotypes tolerant to cold temperature and evaluated the chilling tolerance based on chilling sensitivity under controlled environment. Exceptionally long days (24 hrs photoperiod) and 25/15°C day/night temperatures were given for synchronous flowering for one month after sowing and these plants were subjected to lower temperature 15/5°C and 18 hrs photoperiod at the flower buds appearance stage. The change in thermal regime to 15/5 °C, induces flower abortion in susceptible genotypes. Cold tolerance is available in wild species such as *Cicer bigugum*, *C. pinnatifidum*, *C. echinospermum* and *C. reticulatum*, which are characterization by spreading growth habit, dwarf and small leaflet size, small seed size and with medium to late maturity types. Since these characters are not of more use is commercial varieties, therefore, efforts should be made to utilize these genes of these traits for breeding cold tolerant chickpea genotypes (Singh *et al.*, 1990). It is attributed that cold tolerance in chickpea is probably due to increased concentration of sugars in leaves that acts as osmoprotectants (Basu and Singh, 2003). It is estimated the low temperatures and frost cause losses in chickpea production to a tune up to 100%. In summary it may be concluded that:

- Chickpeas won't hold a pod until average daily temperature reaches to 15°C
- Canopy temperature, rather than daily mean temperature records may be taken into account to explain why flowers and pods abort in chickpea at low temperature.
- Crop must be sown at the optimum time of sowing to maximize WUE and yield and to minimize frost damage.
- Early planting can lead to excessive biomass production, reduced WUE and increased frost damage.



### High Temperature Stress

High temperature during reproductive phase and seed developments affects the seed setting and seed size adversely, and it becomes aggravated if the drought condition prevails during this period.

Chickpea is very sensitive to high temperature, particularly during full blooming stage (Saxena *et al.*, 1988). A few days of exposure to high temperature (30-35°C) causes heavy yield losses. Heat stress may affect the structural integrity of the protein in cytoplasm, and may cause denaturation and aggregation of membrane proteins (Levit, 1969), and reduction in photosynthesis and nitrogen fixation ability of crop (Black *et al.*, 1978). Expression of heat shock protein has been reported in chickpea under heat stress (Sairam and Tyagi, 2004). Methods for screening of germplasms for membrane integrity under stress conditions have been explained by Sullivan and Ross, (1979). Temperature induction (acclimation) response (TIR), which is based on the concept that stress-responsive genes are expressed only during initial stages of stress (acclimation stress) and bring about requisite changes in cell metabolism for adaptation of plants, has also been suggested to identify thermo tolerant crops and their genotypes and its use as a potential screening method has also been advocated (Senthil-Kumar *et al.*, 2007). Utilizing TIR analysis technique, thermotolerant and susceptible lines have been differentiated in peas (Srikanthbabu *et al.*, 2002), groundnut (Srikanthbabu, 2004), and pigeonpea (Annapoornamma, 2003). There is a need to screen available germplasm at the field level, and to identify traits associated with high temperature stress resistance, particularly at terminal growth stage, in this crop. Effort should be made to develop terminal high temperature stress resistant, high yielding varieties utilizing conventional breeding methods and biotechnological tools.

### Effect of Salinity and Seed Priming under Saline Condition

*Cicer arietinum* is one of the most important grain legumes traditionally cultivated in deprived areas and saline soil. At ICRISAT, India, large variations in salinity tolerance were recorded in chickpea genotypes, and relative sensitivity varies with the developmental stage of the crop. It is also observed that the reproductive stage is highly sensitive to salinity in this crop. Among the genotypes evaluated, *desi* genotypes had higher salinity tolerance than *kabuli* types. Seed priming gives better results, when seeds are sown under stored soil moisture condition. From primed seeds, seedling emergence is faster and vigorous. In Bangladesh and India, crop from primed seeds flowered and matured earlier and gave higher yield as compared to that from non-primed seeds (Harris and Kumar Rao, 2005). The better performance of primed seeds has been attributed to the modification in the seed water binding properties and reorganization of seed water during imbibition, so as to increase the macromolecular mobility related to germination process (Nagarajan *et al.*,



2005). Seed priming is reported to induce respiration (Smok *et al.*, 1993) and enhance the synthesis of protein, RNA and DNA during priming (Bray, 1995).

Osmo and hydro priming of chickpea seed with water and mannitol (4%) alleviated the adverse effect of water deficit and salt stress on seedling growth (Kaur *et al.*, 2002a; Vadez *et al.*, 2007). Seeds of different cultivars were soaked with NaCl (halo priming), water (hydro priming) and mannitol (osmo priming) for 8, 16 and 24 hrs. Such primed seeds, when sown in a saline soil (ECe 2.68 dS m<sup>-1</sup>), total dry matter accumulation between halo and hydro priming treatments did not differ up to 80 days after sowing. However, the highest dry matter was produced from halo priming treatment (increased with 37.9% and 16.7%, respectively, relative to osmo and hydro-priming). A similar trend was observed for leaf dry matter accumulation. However, the maximum leaf area (1489.7 cm<sup>2</sup>) was obtained from halo priming treatment at 94 days after sowing. Results showed an increase of 63.6 and 44.7% in yield by halo priming treatment as compared with osmo priming and hydro priming treatments, respectively.

### Effect of Nutrient Deficiencies and Toxicities

Micronutrients play a major role in growth, development, nitrogen fixation and grain yield in chickpea, but earlier no much attention was paid on this aspect. Importance of micronutrients has now been realized, and micronutrients are supplied through organic matter, compost and as inorganic fertilizers. Chickpea yield is affected by iron (Fe), zinc (Zn), molybdenum (Mo) deficiency and by boron (B) toxicity. Recently Jain *et al.* (2009), Rathi *et al.* (2009) showed the improvement in yield of pulses by supplying the micronutrients along with biofertilizers. Nitrogen application (1% aqueous solution of urea) enhanced the grain yield, when applied at flowering and 10 days after flowering under pot culture (Panwar and Singh, 2008) and field conditions (Singh *et al.*, 2008). Iron deficiencies may cause interveinal chlorosis in younger leaves, and uniform yellow-green colour (Smith and Pieters, 1983). Genotypic variations have also been reported in chlorophyll content and yield losses in chickpea (Chaturvedi unpublished data, personal communication). The Mo deficiency causes leaf altering and chlorotic interveinal mottling of older leaves along with poor nodulation. (Nautiyal *et al.*, 2005). Deficiency of zinc in chickpea caused reduced internodes causing rosette type growth, pale green leaflets followed by red brown pigmentation (Smith and Pieters, 1983), and yield losses may vary from 22-50%. However, Boron (B) toxicity may cause up to 100% yield loss (Ali *et al.*, 2002) and the symptoms are observed in the form of yellowing of tips and serrated margins of leaflets (Smith and Pieters, 1983).

### Yield Response to Elevated CO<sub>2</sub>

The positive response of enhanced CO<sub>2</sub> concentration has been reported in number of crop species such as in soybean, dry beans (Prasad and Dwivedi, 2002), peanut (Clifford *et al.*, 1993; 2000), cowpea (Ahmed *et al.*, 1993), mungbean (Sharma Natu *et al.*, 2004). In peanut, CO<sub>2</sub> enrichment experiments showed increased dry matter production and pod yield but had no effect on harvest index (Clifford *et al.*, 1993). No interaction

was found between temperature and CO<sub>2</sub> on seed yield or harvest index in soybean, but seed yield decreased at higher temperature (Prasad *et al.*, 2005; Khaterpal *et al.*, 2009) in chickpea, and seed set in dry bean (Prasad and Dwivedi, 2002), and cowpea (Hall *et al.*, 1992). Elevated CO<sub>2</sub> decreased nitrogen and protein in some legumes also, but such reduction has not been noticed when the crops were fertilized by sufficient nitrogen.

The upper limit for CO<sub>2</sub> effects on economic yield is set by the increase in net C gain, but economic yield also depends on partitioning of assimilated carbon among plant organs. Most studies report little effect of CO<sub>2</sub> enrichment on carbon partitioning and harvest index (Chaudhuri *et al.*, 1986), but both increases and decreases in harvest index have also been reported (Baker, 1989; Ziska *et al.*, 1996).

### REFERENCES

- Aggarwal, P. K.; Khanna Chopra, R. and Sinha, S. K. 1984. Changes in leaf water potential in relation to growth and dry matter production. *Indian J. Exp. Biol.* **22**: 98-101.
- Ahmed, F. E.; Hall, A. E. and Madore, M. A. 1993. Interactive effects of high temperature and elevated carbon dioxide concentration on cowpea [*Vigna unguiculata* (L.) Walp.]. *Plant Cell Environ.* **16**: 835-42.
- Ali, M. Y.; Krishnamurthy, L.; Saxena, N. P.; Rupela, O. P.; Kumar, J.; and Johansen, C. 2002. Scope and genetic manipulation of mineral acquisition in chickpea. *Plant Soil.* **245**: 123-24.
- Annapoornamma, C. J. 2003. Evaluation of pigeon pea (*Cajanus cajan* L.) genotypes for thermotolerance and cross-protection through temperature induction response (TIR) technique. M. Sc. Thesis, University of Agricultural Sciences, Bangalore, India.
- Anonymous, 2000. ACIAR/ICAR Report 1999-2000.
- Anonymous. 2007a. FAO. 2007. *Production Year Book 2007*. F A O of United States, Rome, Italy
- Anonymous. 2007b. ICRISAT News Letter. 2007. Chickpea. <http://www.icrisat.org/chickpea/chickpea.htm>
- Anonymous. 2008. Ministry of Agriculture, Govt. of India, 2008.



- Austin, R. B.; Eldrich, J. A.; Ford, M. A. and Blackwell, R. D. 1977. The fate of dry matter, carbohydrate and  $^{14}\text{C}$  loss from leaves and stem of wheat during grain filling. *Ann. Bot.* **41**: 1309-21.
- Bajaj, S.; Targolli, J.; Liu LF, H. O. and Wu, R. 1999. Transgenic approach to increase dehydration stress tolerance in plants. *Mol. Breed.* **5**: 493-503.
- Baker, F. W. G. 1989. Conclusion in drought resistance in cereals. Baker F. W. G. (Ed.). ICSU Press, Paris, pp. 213-20.
- Basu, P. S. and Singh, D. N. 2003. Physiology and abiotic stresses in chickpea. *In: Chickpea Research in India*. Ali M., Kumar Shiv and Singh N. B., (Eds). IIPR, Kanpur, pp. 137-166.
- Berry, J. A. 1975. Adaptation of photosynthetic processes to stress. *Science*. **186**: 664-50.
- Bewley, J. D. 1979. Physiological aspects of dessication tolerance. *Ann. Rev. Plant Physiol.* **30**: 195-238.
- Bhattacharya, A. and Singh, D. N. 1999. Physiological studies in chickpea varieties; photosynthesis and allied parameter under normal and late sowing. *Indian J. Pulses Res.* **12**: 211-20.
- Bidinger, F. R.; Chandra, S. and Mahalaxmi, V. 2000. Genetic improvement of tolerance to terminal drought stress in pearl millet. *In: Proceedings on Strategies Planning Workshop at CIMMYT Elbaton, Maxico*. Ribaut J. M. and Poland D., (Eds). 21-25 June, pp. 59-63.
- Bidinger, F. R.; Musgrava, R. V. and Fisher, R. A. 1977. Contribution of stored pre-anthesis assimilate to grain yield in wheat and barley. *Nature*. **270**: 894-900.
- Bidinger, F. R.; Yadav, O. P. and Sharma, M. M. 2002. Male sterile seeds parents for breeding landrace-based top cross hybrids of pearl millet for arid zone. I. Productivity, responsiveness and stability. *Indian J. Gen. Plant Breed.* **62**:121-27.
- Black, C. C.; Brown, R. H. and Moore, R. C. 1978. Plant photosynthesis. *In: Limitations and Potentials for Biological Nitrogen Fixation in the Tropics*. Dobereineer J., Burnes R.M. and Hollander A., (Eds). Plinum Press, New York, USA.
- Blum, A. 1988. *Plant Breeding for Stress Environment*. CRC Press, Boca Raton. FL.
- Blum, A. 1996. Crop response to drought and the interpretation to adaptation. *Plant Growth Regulation*, **20**: 135-48.
- Blum, A. 2005. Drought resistance, water use efficiency, and yield potential: are they compatible, dissonant, or mutually exclusive? *Australian J. Agric Res.* **56**: 1159-68.
- Blum, A.; Zhang, J. X. and Nguyen, H. T. 1999. Consistent differences among

wheat cultivars in osmotic adjustment and their relationship to plant production. *Field Crop Res.* **64**: 287-91.

Blum, A.; Mayer, J. and Golan, G. 1983. Chemical dessication of wheat plants as a stimulator of post anthesis stress: Relation to drought stress. *Field Crop Res.* **6**: 140-55.

Boyer, J. S. 1976. Photosynthesis at low water potential. *Philos. Trans. Royal Soc. London. Ser B* **21**: 501-12.

Bradford, K. J. 2004. Seed technology and enhancement. *Seed Production Quality*, pp. 112 -17.

Bray, C. M. 1995. Biochemical processes during osmopriming of seeds. *In: Seed Development and Germination*. Kigel J. and Golili G., (Eds). Marcel Dekker, New York, pp. 767-789.

Bushby, H. V. A. and Lawn, R. J. 1992. Accumulation of partitioning of N and dry matter by contrasting genotypes of mungbean. *Australian J. Agric. Res.* **43**: 1609- 28.

Chaudhuri, U. N.; Burnett, R. B.; Kirkham, M. B. and Kanemasu, E. T. 1986. Effect of carbon dioxide on sorghum yield, root growth, and water use. *Agric. For. Meteorol.* **37**: 109-22.

Clifford, P. E.; Marshall, C. and Sagar, G. R. 1993. An examination of the value of  $^{14}\text{C}$  urea as a source of  $^{14}\text{CO}_2$  for studies of assimilate distribution. *Ann. Bot.* **37**: 37-44.

Clifford, S. C.; Stronach, I. M.; Black, C. R.; Singleton-Jones, P. R.; Azam-Ali, S. N. and Crout, N. M. J. 2000. Effect of elevated  $\text{CO}_2$ , drought and temperature on water relation and gas exchange of groundnut (*Arachis hypogaea*) stands grown in environmental glasshouse. *Physiol. Plant.* **110**: 78-88.

Condon, A. G.; Richards, R. A. and Farquhar, G. D. 1987. Carbon isotope discrimination is positive correlation with grain yield and dry matter production in field-grown wheat. *Crop Sci.* **27**: 996-1001.

Condon, A. G.; Richard, R. A.; Rebetzke, G. J. and Farquhar, G. D. 2002. Improving intrinsic water use efficiency and crop yield. *Crop Sci.* **42**: 122-31.

Davies, S. L.; Turner, N. C.; Palta, J. A.; Siddique, K. H. M. and Plummer, J. A. 2000. Efficient remobilization of carbon and nitrogen support seed filling in the chickpea subjected to water deficit. *Australian J. Agric Res.* **51**: 855- 66.

Davies, S. L.; Turner, N. C.; Siddique, K. H. M.; Plummer, J. A. and Leport, L. 1999. Seed growth of desi and kabuli chickpea in short season mediterranean type environment. *Australian J. Exp. Agric.* **39**: 181-88.

Deshmukh, P. S.; Mahase, L. B. and Jamadagni, B. M. 2004a. Evaluation of chickpea genotypes for drought tolerance. *Indian J. Pulses Res.* **17**: 47-49.

Deshmukh, P. S.; Sairam, R. K.; Shukla, D. S. and Wasnik, K. G. 1996. Screening of wheat genotypes to high temperature stress tolerance.



*Proceedings of National Symposium of Plant Physiology*, Imphal, 15-17 Dec., 1995, pp 1-6.

Deshmukh, P. S.; Singh, Tejpal; Kushwaha, S. R.; Rao, L. S.; Turner, N. C.; Yadav, S. S. and Kumar, J. 2004b. Effect of delayed planting on membrane injury and yield of six chickpea genotypes. *Fourth International Crop Science Congress 2004*, Australia.

Doorenbos, J. and Pruitt, W. O. 1975. Guidelines for predicting crop water requirements. FAO Irrigation & Drainage paper No. 24, FAO, Rome, Italy.

Dua, R. P.; Chaturvedi, S. K. and Shiv, S. 2001. Reference variety of chickpea for IIPR, Kanpur Regime. IIPR Kanpur, India, Report. 1-34

Fischer, K. S.; Johansen, E. C. and Edmeades, G. O. 1982. Breeding and selection of drought resistance in tropical maize. *In: Drought Resistance in Crops with Emphasis on Rice*. IRRI, Philippines, pp. 377-99.

Fisher, R. A. 1979. Growth and water limitation to dry land wheat in Australia: A physiological frame work. *J. Australian Inst. Agric. Sci.* **45**: 83-94.

Fischer, R. A. and Turner, N. C. 1978. Plant productivity in the arid and semi-arid zones. *Ann. Rev. Plant Physiol.* **29**: 277-317.

Flower, D. J. and Ludlow, M. M. 1986. Contribution of osmotic adjustment to the dehydration tolerance of water stress pigeonpea (*Cajanus cajan* (L.) Millsp.). *Plant Cell Environ.* **9**: 33-40.

Flower, D. J. and Ludlow, M. M. 1987. Variation among accessions of pigeonpea (*Cajanus cajan*) in osmotic adjustment and dehydration tolerance of leaves. *Field Crops Res.* **17**: 229-43.

Gaff, D. E. 1980. Protoplasmic tolerance of extreme water stress. *In: Adaptation of Plants to Water and High Temperature Stress*. Turner N. C. and Kramer P. J., (Eds). Wiley, New York, pp. 207-30.

Galston, A. W.; Kaur-Sawhney, R.; Altabella, T. and Tiburico, A. F. 1997. Plant polyamines in reproductive activity and response to abiotic stress. *Bot. Acta.* **110**: 197-207.

Grover, A.; Koundal, K. R. and Sinha, S. K. 1985. Senescence of attached leaves: Regulation by developing pods. *Physiol. Plant.* **63**: 87-92.

Gopalan, C.; Rama Sahtri, B. V. and Balasubramanian, S. C. 1985. *Nutritive Value of Indian Foods*. ICMR Publication. Revised and update in 1989 by B. S. Narasinga Rao; Y. G. Deosthale and K. C. Pant. (reprinted 2007).

Gupta, S. C. and Namdeo, S. L. 1996. Effect of *Rhizobium* strains on symbiotic traits and grain yield of chickpea. *Indian J. Pulses Res.* **9**: 94-950.

Gupta, S. C. and Panwar, J. D. S. 2006. Morphological effects of thermal and moisture stress on chickpea genotypes. *Indian J. Plant Physiol.* **11**: 213-216.

Hall, A. E.; Mutter, R. G. and Farquhar, G. D. 1992. Genotypic and drought induced differences in carbon isotopic discrimination and gas exchange in cowpea. *Crop Sci.* **32**: 1-6.

- Hardy, R. W. F.; Havelika, V. D and Quebedeaux, B . 1977. Increasing crop productivity: The problem, strategies, approaches and selected limitation to photosynthesis. *Proceedings of fourth Congress on Photosynthesis*, pp. 695.
- Harris, D. and Kumar Rao, J. V. D. 2005. Rainfed rabi cropping in rice –fellow chickpea in eastern India. A development brief by the centre for arid zone studies and ICRISAT.
- Hsaio, T. C.; O'Toole, J. C.; Yambao and Turner, N. C. 1984. Influence of osmotic adjustment on leaf rolling and tissue death in rice. *Plant Physiol.* **75**: 338-341.
- Jain, A. K.; Panwar, J. D. S. and Sudhir Kumar. 2009. Plant growth promoting *Rhizobacteria* in crop plants against pests and diseases. *In: Plant Disease Management for Sustainable Agriculture*. Ahmed Sabid, (Ed.). Daya Publishing House, New Delhi, pp. 299-327.
- Kakkar, R. K. and Sawhney, V. K. 2003. Polyamine research in plants-a changing perspective. *Plant Physiol.* **116**: 281-292.
- Kao, C. H. 1997. Physiological significance of stress induced changes in polyamines in plants. *Bot. Bull. Acad. Aci.* **38**: 141-144.
- Kashiwagi, J.; Krishnamurthy, L.; Singh, Sube; Gaur, P, M.; Upadhy, H. D.; Panwar J. D. S.; Basu, P. S.; Ito, O. and Tobia, A. 2006. Relationship between transpiration and carbon isotope discrimination in chickpea. *International Chickpea and Pigeonpea News Letter*, 2006. **13**: 19-20.
- Kaur, S.; Gupta, N. K. and Kaur, N. 2002a. Effect of hydro and osmopriming of chickpea seed on crop performance in field. *International Chickpea and Pigeonpea Newsletter.* **9**: 15-16.
- Khanna-Chopra, R. and Vidya, I. 1987. Photosynthetic rate does not correlate with dry matter accumulation in chick pea. *Photosynthetica.* **53**: 545-49.
- Khanna-Chopra, R. and Sinha, S. K. 1982. Photosynthesis rate and photosynthetic carboxylases during growth and development in Bengal gram cultivars. *Photosynthetica.* **16**: 509-13.
- Khaterpal, S. Pal, M. and Lata, S. 2009. Effect of elevated temperature on growth and physiological characters in chickpea. *Indian J. Plant Physiol.* **14**: 377-83.
- Krishnamurthy, L.; Johansen, C. and Ito, O. 1996. Genetic variation in root system development and its implication for drought resistance in chickpea *In: Roots and Nitrogen in Cropping System of the Semi Arid Tropics*. Adu-Gyamfi J. J., Katayama K., Kumar Rao J. V. D. K. and Rego T., (Eds). Research Centre for Agric. Sci. (Jircas) Ibasaki, Japan, **3**: 235-50.
- Kumar, S.; van Rheenen, H. A. and Singh, O. 1999. Genetic analysis of different components of crop duration in chickpea. *J. Genetics Pl Breeding.* **53**: 189-200.
- Lawn, R. J. 1982. Response of four grain legumes to water stress in southeastern



Queensland: Physiological response mechanism. *Australian J. Agric. Res.* **33**: 481-96.

Lazcano-Ferrat, I. and Lovatt, C. J. 1999. Relationship between relative water content, nitrogen pool and growth of *Phaseolus vulgaris* and *P. acutifolius* during water deficit. *Crop Sci.* **39**: 476-75.

Lecoeur, J.; Wery, J. and Ture, O. 1992. Osmotic adjustment as a mechanism of dehydration postponement in chickpea (*Cicer arietinum* L.) leaves. *Plant Soil.* **144**: 177-89.

Lee, T. M. 1997. Polyamine regulation of growth and chilling tolerance of rice root cultured in *in vitro*. *Plant Sci.* **122**: 111-17.

Leport, L.; Turner, N. C.; French, R. J.; Barr, M. D.; Duda, R.; Davies, S. L.; Tennant, D. and Siddique, K. H. M. 1999. Physiological response of chickpea genotypes to terminal drought in a mediterranean environment. *European J. Agron.* **11**: 279-91.

Levitt, J. 1969. Growth and survival of plants of extremes of temperature; a unified concept. *Soc. Expt. Biol. Symp.* **23**: 395-448.

Ludlow, M. M. and Muchow, R. C. 1990. A critical evaluation of the traits for improving crop yield in water limited environments. *Adv. Agron.* **43**: 107-153.

Ludlow, M. M.; Santamana, J. M. and Fukai, S. 1990. Contribution of osmotic adjustment to grain yield of *Sorghum bicolor* (L.) Moench. under water limited conditions. II. Water stress after anthesis. *Australian J. Agric. Res.* **41**: 67-78.

Ma, Q.; Behboudian, M. H.; Turner, N. C. and Palta, J. A. 2001. Gas exchange by pods and subtending leaves and internal recycling of CO<sub>2</sub> by pods of chickpea (*Cicer arietinum* L.) subjected to water deficits. *J. Exp. Bot.* **52**: 123-131.

Meckel, L.; Egli, D. B.; Philips, R. E.; Redcliffe, D. and Legget, J. E. 1984. Effect of moisture stress on seed growth in soybean. *Agron. J.* **76**: 647-650.

Meyer, R. F. and Boyer, J. S. 1981. Osmoregulation, solute distribution and growth in soybean seedlings having low water potential. *Planta.* **151**: 482-489.

Mohapatra, P. K.; Turner, N. C. and Siddique, K. H. M. 1997. Assimilate partitioning in chickpea in drought prone environment. *In: Management of drought in grain legume.* (N. P. Saxena and C. Johansen, eds.). ICARDA Aleppo, Syria.

Moinnuddin and Chopra, R. K. 2004. Osmotic adjustment in chickpea in relation to seed yield and yield parameters. *Crop Sci.* **44**: 449-55.

Morgan, J. M. and King, R. W. 1984. Association between loss of leaf turgor, abscisic acid levels and seed set in two wheat cultivars. *Australian J. Plant Physiol.* **11**: 143-150.

Morgan, J. M. 1983. Osmoregulation as selection criteria for drought tolerance in wheat. *Australian J. Agric. Res.* **34**: 607-614.

- Morgan, J. M. 1995. Growth and yield of wheat at high soil water deficit in seasons of varying evaporative demand. *Field Crop Res.* **40**:143-152.
- Morgan, J. M., Rodriguez-Maribana, B. and Knights, E. J. 1991. Adaptation to water deficit in chickpea breeding lines by osmoregulation, relationship to grain yield in fields. *Field Crops.* **27**: 61-70.
- Nagarajan, S.; Pandita, V. K.; Joshi, D. K.; Sinha, J. P. and Modi, B. S. 2005. Characterization of water status in primed seeds of potato by sorption properties and NMR relaxation times. *Seed Sci. Res.* **15**: 1-4.
- Nageshwara Rao, R. C. and Wright, G. C. 1994. Stability of relationship between specific leaf area and carbon isotope discrimination across environment in peanut. *Crop Sci.* **34**: 98-103.
- Nautiyal, S.; Singh, S. and Chatterjee, C. 2005. Seed reserves of chickpea in relation to molybdenum supply. *J. Sci. Food Agric.* **85**: 860-64.
- Nayyar, H. and Chander, S. 2004. Protective effect of polyamines against oxidative stress induced by water and cold stress in chickpea. *J. Agron Crop Sci.* **190**: 431-38.
- Nayyar, H.; Kaur, S.; Smita; Kumar, S.; Singh, K. J. and Dhir, K. K. 2005. Involvement of polyamine in the contrasting sensitivity of chickpea and soybean to water deficit stress. *Bot. Bull. Acad. Sin.* **46**: 333-338.
- Nicolas, M. E. and Turner, N. C. 1993. Use of dessicant and chemical senescing agents to select wheat lines maintaining stable grain size during post-anthesis drought. *Field Crops Res.* **31**: 155-71.
- Pandey, R. K.; Saxena, M. C.; Singh, V. B. and Singh, K. B. 1978. Assimilation and utilization of  $^{14}\text{C}$  assimilates in chickpea. *J. Nuclear Agric. Biol.* **7**: 56-60.
- Panwar, J. D. S. 2006. Advancing fine root research using mini rhizotron. *ICAR News Letter.* **12**: 2-3.
- Panwar, J. D. S. and Singh, Atar. 2008. Effect of urea application on growth and seed quality in four chickpea varieties. In: *Souvenir*. 42<sup>th</sup> Foundation Day of the Division of Plant Physiology, IARI, New Delhi. 14<sup>th</sup> Nov. 2008, pp. 37-39.
- Passioura, J. B. 1982. The role of root system characteristics in the drought tolerance of crop plants. In: *Drought Resistance in Crops with Emphasis on Rice*. IRRI, Philippines, pp. 71-82.
- Passioura, J. B. 1983. Root and drought resistance. *Agric Water. Manag.* **7**: 265-80.
- Pate, J. S.; People, M. B.; vanBel, A. R. E.; Kno, J. and Atkin, C. A. 1985. Diurnal water balance of cowpea fruits. *Plant Physiology.* **77**: 148-56.
- Polley, H. U. 2002. Implication of atmospheric and climatic change for crop yield and water use efficiency. *Crop Sci.* **42**: 131-40.



- Prasad, V. V. S.; Pandey, R. K. and Saxena, M. C. 1978. Physiological analysis of yield variation in gram genotype. *Indian J. Plant Physiol.* **21**: 228-34.
- Prasad, K. and Dwivedi, B. S. 2002. Effect of legume introduction in rice wheat system in crop productivity in upper gangetic plain zone of India. 2<sup>nd</sup> International Congress in Agronomy, 26-30 November 2002.
- Prasad, K.; Kumar, S.; Pyre, S. and Rathi, J. P. S. 2005. Effect of FYM and biofertilisers in conjunction with inorganic fertilizer on growth, yield of chickpea. *J. Intracedemicia*. **9**: 183-87.
- Rathi, B. K.; Jain, A. K.; Kumar, S. and Panwar, J. D. S. 2009. Response of rhizobium inoculation with sulphur and micronutrients on yield and yield attributes of black gram. *Legume Res.* **32**: 62-64.
- Rawson, H. M.; Bagga, A. K. and Bremner, P. M. 1977. Aspects of adaptation by wheat and barley to soil moisture deficit. *Australian J. Plant Physiol.* **4**: 389-401.
- Roberts, D. R.; Dumbroff, E. B. and Thompson, J. E. 1986. Exogenous polyamine alter membrane fluidity in bean leaves-a basis for their potential misinterpretation of their true physiological role. *Planta*. **167**: 395-401.
- Sairam, R. K. and Tyagi, A. 2004. Physiology and molecular biology of salinity stress tolerance in plants. *Curr. Sci.* **86**: 407-21.
- Sandhu, J. S. and Arasakesay, S. J. 2003. Evaluation of chickpea genotypes for cold tolerance. *International Chickpea, Pigeonpea Newsletter*. **10**: 9-12.
- Santakumari, M.; Reddy, C. S.; Reddy, A. R. C. and Das, V. S. R. 1979. CAM behaviour in grain legume, chickpea. *Natunvissenshaften* **66**.
- Saxena, M. C.; Saxena, N. P. and Mohammed, A. K. 1988. High temperature stress. In: *World Crops: Cool Season Food Legumes*. Summerfield R.J., (Ed.) Kluwer Academic Publisher: Dordrecht, The Netherlands.
- Saxena, N. P. and Johansen, C. 1990. Chickpea ideotype for genetic improvement in yield and yield stability in South Africa. In: *Chickpea in Nineties*. ICRISAT, Hyderabad, pp. 81-85.
- Saxena, N. P. 1984. The physiology of tropical field crops. Goldsworthy P. R. and Fisher N. M., (Eds). Wiley, New York, pp. 419-452.
- Saxena, K. B.; Wallis, E. S. and Byth, D. E. 1983. A new gene for male sterility in pigeonpea. *Heredity*. **51**: 419-21.
- Schnyder, H. 1993. The role of carbohydrate storage and redistribution in the source sink relation of wheat and barley during grain filling -a review. *New Phytol.* **123**: 233-45.
- Schwab, K. S. and Heber, U. 1984. Thylakoid membrane stability in drought tolerant and drought susceptible plants. *Planta*. **161**: 37-45.
- Senthil-Kumar, M.; Kumar, G.; Srikanthbabu, V. and Udayakumar, M. 2007. Assessment of variability in acquired thermotolerance: Potential option to

study the genotypic response and the relevance of stress genes. *J. Plant Physiol.* **164**: 111-25.

Serraj, R. and Sinclair, T. R. 2002. Osmotic adjustment: Can it really help increase yield under drought condition? *Plant Cell Environ.* **25**: 333-41.

Shackel, K. A. and Turner, N. C. 2000. Seed coat cell turgor in chickpea is independent of changes in plant and pod water potential. *J. Exp. Bot.* **51**: 895-900.

Shaha, Kunal and Aggarwal, Anju (Nirmal Bang). 2010. Indian Agriculture Review, Ghana. Outlook. pp. 1-24. <<[http://www.stockmarketreview.com/commodities/Indian\\_agriculture\\_review\\_ghana](http://www.stockmarketreview.com/commodities/Indian_agriculture_review_ghana) 2009>>

Sharma Natu, Poonam; Vijai P. and Ghildiyal, M. C. 2004. Photosynthetic acclimation and productivity of mungbean cultivars under elevated CO<sub>2</sub> concentration. *J. Agron. Crop Sci.* **190**: 81-85.

Sheldrake, A. R. and Narayanan, A. 1979. Growth, development and nutrient uptake in pigeonpea. *J. Agric. Sci.* **92**: 513-526.

Sheoran, I. S.; Singhal, H. R. and Singh, R. 1987. Photosynthetic characteristics of chickpea pod wall during seed development. *J. Exp. Biol.* **25**: 843 -847.

Siddique, K. H. M.; Loss, S. P. and Thompson, B. D. 1997. Cool season grain legumes in dry land Mediterranean environment of western Australia: Significance of early flowering. In: *Management of Drought in Grain Legumes*. Saxena N. P. and Johansen C., (Eds). ICARDA, Aleppo, Syria, pp. 189-99.

Siddique, K. H. M.; Loss, S. P.; Regan, K. L. and Jettner, R. 1999. Adaptation of cool season legumes in Mediterranean type environments of South Western Australia. *Australian J. Agric. Res.* **50**: 375-87.

Siddique, K. H. M.; Sedgley, R. H. 1986. Chickpea- a potential grain legume for South Western Australia: Seasonal growth and yield. *Australian J. Agric. Res.* **37**: 245-51.

Sinclair, T. R. and Ludlow, M. M. 1986. Influence of soil water supply on plant water balance of four tropical legumes. *Australian J. Plant Physiol.* **13**: 329-41.

Singh, A.; Nirwal, J. and Panwar, J. D. S. 2008. Effect of foliar spray of urea on grain quality and grain yield of chickpea cultivars under rainfed condition. *Proceedings of National Symposium*, IARI, New Delhi, 14-17 September 2008.

Singh, K. B. and Pandey, R. K. 1980. Production and distribution of assimilates in chickpea (*Cicer arietinum* L.). *Australian J. Plant Physiol.* **7**: 727-35.

Singh, K. B.; Malhotra, R. S. and Saxena, M. C. 1990. Sources for tolerance to cold in *Cicer* sp. *Crop Sci.* **30**: 1136-38.

Singh, M.; Srivastava, J. P. and Kumar, A. 1992. Cell membrane stability in relation to drought tolerance in wheat genotypes. *J. Agron. Crop Sci.* **168**: 186-90.



Sinha, S. K. 1977. Food legumes: distribution, adaptability and biology of yield. FAO Plant Production and Protection Pap. 3. Rome, pp. 124

Sinha, S. K.; Lal, B.; Koundal, K. R. and Khanna-Chopra, R. 1983. Nitrogen fixation does not limit yield in pulses. *Current Sci.* **52**: 916-918.

Smith, F. W. and Pieters, W. H. J. 1983. Foliar symptoms of nutrient disorder in chickpea. CSIRO Division of Tropical Crops and Pastures. Technical paper 23. Melbourne, Australia CSIRO.

Smok, M. A.; Chojnowski, M.; Corbineari, F. and Come, D. 1993. Effect of osmotic treatment on sunflower seed germination in relation with temperature and oxygen. In: IV International Workshop on Seeds. Basic and applied aspects of seed biology. Come D. and Corbineri F., (Eds). Paris, ASFIS, **3**: 1033-1038.

Srikanthbabu, V. 2004. Identification of thermotolerant lines from the mutated population of groundnut (*Arachis hypogaea* L.) based on temperature induction response and expression of HSFs and HSPs. Ph. D. Thesis, University of Agricultural Sciences, Bangalore, India.

Srikanthbabu, V.; Kumar, G.; Krishnaprasad, B. T.; Gopalakrishna, R.; Savitha, M. and Udayakumar, M. 2002. Identification of pea genotypes with enhanced thermotolerance using temperature induction response (TIR) technique. *J. Plant Physiol.* **159**: 535-45.

Srinivasan, A.; Takeda, H. and Senboku, T. 1996. Heat tolerance in food legumes as evaluated by cell membrane thermostability and chlorophyll fluorescence techniques. *Euphytica.* **88**: 35-45.

Srinivasan, A.; Saxena, N. P. and Johansen, C. 1998. Cold tolerance during early reproductive growth of chickpea. (*Cicer arietinum* L.): Growth variation in gamete development and function. *Field Crop Res.* **60**: 209-22.

Srinivasan, A.; Johansen, C. and Saxena, N. P. 1999. Cold tolerance during early reproductive growth in chick pea. Genetic variation in gamete development and function. *Field Crop Res.* **61**: 195-200.

Subbarao, G. V.; Johansen, C.; Shrikard, A. E.; Rao, R. C. N.; Saxena, N. P. and Chauhan, Y. S. 1995a. Strategies for improving drought resistance in grain legumes. *Critical Rev. Plant Sci.* **14**: 469-523.

Subbarao, G. V.; Johansen, C.; Nageswar Rao, R. C. and Wright, G. C. 1995b. Transpiration efficiency: Avenues for genetic improvement. *In: Handbook of Plant and Crop Physiology.* Pessarakali M., (Ed.). Marcel Dekker Inc. New York, pp. 785-806.

Sullivan, C. Y. and Ross, W. M. 1979. Selecting for drought and heat resistance in grain Sorghum. *In: Stress Physiology in Crop Plants.* Mussell H. and Staples, (Eds). John Wiley, New York, USA.

Thovaragah, D. and Ball, R. A. 2006. Drought induced changes in free amino acid and ureide concentration of nitrogen fixing chickpea. *Canadian J. Plant Sci.* **86**: 149-56.

Turner, N. C. 1979. Drought resistance and adaptation to water deficit in crop

plants. *In: Stress Physiology in Crop Plants*. Mussels H. and Staples R. C., (Eds). Wiley, New York, pp. 343-72.

Turner, N. C. 1991. Measurements and influence of environmental and plant factors on stomatal conductance in the field. *Agric. Forest Meteorol.* **54**: 137-54.

Turner, N. C. 1993. Water use efficiency of crop plants: Potential for improvement. *In: International Crop Science I. Madison*: Crop Science Soc. America. Buxton D. R., Shibles R., Forsberg R. A., *et al.*, (Eds), pp. 75-82.

Turner, N. C. and Jones, M. M. 1980. Turgor maintenance by osmotic adjustment-A review and evaluation. *In: Adaptation of Plants to Water and High Temperature Stress*. Turner N. C. and Krammer P. J., (Eds). Wiley-Interscience Pub., Johns Wiley & Sons, New York, pp. 87-103.

Turner, N. C. and Whan, B. R. 1995. Strategies for increasing productivity from water limited areas through genetic means. *In: Genetic Research and Education: Current Trends and the Next Fifty Years*. Sharma B., Kulsherestha V. P., Gupta N. and Mishra S. K., (Eds). Indian Soc. Gen. Plant Breeding, New Delhi, India, pp. 545-57.

Turner, N. C.; Shahal, A.; Berger, J. D.; Chaturvedi, S. K.; French, R. J.; Ludurg, C.; Mannur, D. M.; Singh, S. J. and Yadava, H. S. 2007. Osmotic adjustment in chickpea (*Cicer arietinum* L.) results in no yield benefit under terminal drought. *J. Exp. Bot.* **58**: 187-94.

Turner, N. C.; Wright, G. C.; Siddique, K. H. M.. 2001. Adaptation to grain legumes (Pulses) to water limited environment. *Adv. Agron.* **71**:193-231.

Vadez, V.; Krishnamurthy, L.; Serraj, R.; Gaur, P. M.; Upadhyay, H. D.; Hoisington, D. A.; Varshney, R. K.; Turner, N. C. and Siddique, K. H. M. 2007. Large variation in salinity tolerance in chickpea is explained by differences in sensitivity at the reproductive stage. *Field Crop Res.* **104**: 123-29.

van der Maesen, L. J. G. 1972. Cicer, L. A monograph of the genus with special reference to chickpea (*Cicer arietinum* L.). *Trop. Grain Legume Bull.* **6**: 29-31.

Wright, G. C.; Hubick, K. T. and Farquhar, G. D. 1991. Physiological analysis of pea nut cultivars response to timing and duration of drought stress. *Australian J. Agric. Res.* **42**: 453-70.

Zhang, J. K. Wang, Z.; Wu, R.; Ho, D. and Nguyen, H. T. 2000. Genetic engineering for abiotic resistance stress in crop plants *in vitro* cell. *Dev. Biol.* **36**: 108-14.

Ziska, L. H.; Munalo, P. A.; Ordonez, R. A. 1996. Intraspecific variation in the response of rice to increased CO<sub>2</sub> and temperature on growth and yield response of 17 cultivars. *J. Exp. Bot.* **47**: 1353-59.



## CHAPTER-9

# Physiology of Pigeonpea

**P**igeonpea [*Cajanus cajan* (L.) Millsp.] belongs to family Fabaceae. It is also known as *Arhar* (Hindi/Bengali), *Tuvari* (Sanskrit), *Red gram*, *Tur* (Gujarati/Marathi/Punjabi), *Tuvera* (Malayalam), *Kandi* (Telgu), *Tuvaram parappu* (Tamil) and *Rahar* (Nepali). In other parts of the world it is also called as *Yewofater*, *Gandul*, *Guandu*, *Concopea*, *Gungopea* and *one eye pea* (Wikipedia, the free Encyclopedia). It is popularly called as pigeonpea, which is originated from Caribbean, where it was used as a pigeon feed.

The centre of origin of pigeonpea is most likely Asia, from where it reached to East Africa. Due to large genetic variability in local germplasm and existence of numerous wild relatives in India, it is considered as primary centre of origin in Asia (Vavilov, 1951). The probability of tropical Africa being the centre of origin is also mentioned (Anonymous, 2005a). However, India is primary centre of origin of pigeonpea (van der Maesen, 1980). It reached the new world in early post Columbian era. Now pigeonpea is widely cultivated between 30° N and 30° S in tropical and subtropical regions of the world. It is short lived perennial shrub, traditionally cultivated as annual crop.

### Distribution

Pigeonpea is cultivated in more than 25 tropical and subtropical countries either as a sole crop or intercropped. In Asia it is grown in 4.3 m ha and major pigeonpea growing countries are India (3.6 m ha), Myanmar (0.56 m ha), China (0.15 m ha), and Nepal (0.021 m ha). In Africa it is grown in Eastern and Southern parts in a total area of 0.56 m ha, and the major pigeonpea growing countries are Kenya (0.196 m ha), Malawi (0.123 m ha), Uganda (0.086 m ha), Mozambique (0.084 m ha), and Tanzania (0.068 m ha). It is also cultivated in Central America and Australia. During 2005 approximately 3.5 million tonnes of pigeonpea was grown worldwide and 3 million tonnes of this yield were harvested in India. The current global estimate of its annual productivity is estimated to be more than US \$1,700 (Anonymous, 2005b).

Nutritional Composition

Pigeonpea seeds are a good source of dietary fiber, proteins, magnesium, thiamin, phosphorus, potassium and copper and a very rich source of foliate and manganese. It is very low in saturated fats, cholesterol (almost nil) and sodium (1%). Chemical composition and nutritive value of mature pigeonpea seeds are given in Table 1.

Green seeds of pigeonpea are also consumed and are much more nutritious than green pea seeds because on fresh weight basis green seeds of pigeonpea have greater edible portion (72% vs. 53%), carbohydrates, fibre and fat. Green pigeonpea seeds are also having more minerals and very high content of same vitamins (469 vs. 83 vitamin A: 0.30 vs. 0.01 vitamin B<sub>2</sub>, and 25 vs. 9 vitamin C per mg seed). However, a comparison of nutritional composition of green and mature seeds of pigeonpea on dry weight basis is given in Table 1.

**Table 1.** Comparison of nutritional composition of green and mature seeds of pigeonpea on dry weight basis

Constituent	Green seeds	Mature seeds
Protein (%)	21.0	18.8
Protein digestibility (%)	66.8	58.5
Trypsin inhibitor (units/mg)	2.8	9.9
Starch (%)	44.8	53.0
Starch digestibility (%)	53.0	36.2
Amylase inhibitor (units/mg)	17.3	26.9
Soluble sugars (%)	5.1	3.1
Flatulence factors (g/mg soluble sugar)	10.3	53.5
Crude fibre (%)	8.2	6.6
Fat (%)	2.3	1.9
<b>Minerals and trace elements (mg/100 g)</b>		
Calcium	94.6	120.8
Magnesium	113.7	122.0
Copper	1.4	1.3
Iron	4.6	3.6
Zinc	2.5	2.3

Cropping Pattern, Early, Medium and Late Types in India

In India, it is the second most important pulse crop. Besides dietary benefits, it has other uses, viz. fodder, fuel, wood, rearing lack insects, hedges, wind breakers, soil conservation, green manure, roofing, etc. in traditional cropping system, the crop is often sown as inter-crop or mixed with other crops, viz. upland rice, finger millet, sorghum, pearl millet,



maize, peanut, soybean, mungbean, black gram, castor, cotton, sugarcane and cassava, etc.

The crop has immense contribution to nitrogen and carbon economy of the soil (Rega and Nageswara Rao, 2000). The reproductive growth occurs on residual moisture left after companion crop is harvested (Ali, 1990). In peninsular India, where medium duration varieties predominates, terminal drought (reproductive period) is the major yield limiting factor (Chandra Mohan, 1969), while in northern parts of India, where mainly late varieties are cultivated, in the early growth phase crop may experience waterlogging stress, vegetative and early flowering phase frost and late reproductive phase drought.

Crop has a wide range of maturity and on the basis of maturity period it has been categorized into extra early (90-110 days maturity period), early (110-150 days maturity) medium (150-180 days maturity) and late (180-200 days maturity) types. Length of vegetative period is the major difference between such genotypes. For agronomic purposes it is also grouped as compact (erect), semi-spreading (semi-erect) and spreading type (Singh and Oswalt, 1992). On the basis of flowering pattern pigeonpea is classified as determinate, semi-indeterminate and indeterminate types. Late-maturing varieties are semi indeterminate types, while others are either indeterminate or semi-indeterminate types. Medium and long duration varieties contribute to the bulk of production in India and other major pigeonpea growing countries (Ali, 1990). In indeterminate genotypes, flowering initiate at the basal node and proceed acropetally, while in determinate cultivars flowering starts at the apical raceme and proceeds basipetally (Sheldrake and Narayanan, 1979a).

### Nitrogen Fixation and Nutritional Requirement

It is a leguminous crop and fixes atmospheric N by symbiotic association with *Rhizobium* belonging to the “cowpea-miscellany”. Generally, nodulation initiation occurs after 15 days after sowing and continues till pod filling and then declines (Kumar Rao, 1990. Kumar Rao *et al.*, 1996). Nodules differ in shape ranging from 2-4 mm, and size as elongate, oval and spherical. The estimated N fixed in different genotypes depends upon the maturity duration of the crop and ranges from 6 to 69 kg N/ha. However, long duration pigeonpea of 40 weeks growth duration, commonly grown in North India, fixes nearly 200 kg N/ha (Anonymous, 2009). It is estimated that 90% of the plant N in medium-duration pigeonpea, grown as sole crop in black soil, is derived from nodular fixation (Anonymous, 2009). Kumar Rao and Dart (1987) showed a correlation between nodule number and crop size.

The nutritional requirement of the crop is low. During early seedling stage it responds to a “starter dose” of 15 to 20 kg N/ha, but in the later stages most of the N comes from fixation in nodules. In short duration genotype biological nitrogen fixation has been found to be inadequate, and

grain yield increased in response to nitrogen fertilizer applied at flowering stage (Kumar Rao *et al.*, 2008). Crop responds to applied P. Increased yield has been observed on application of 17 to 20 kg P/ha. In some areas application of K and Zn is also recommended. Zinc deficiency is corrected by the application of 15 kg Zn/ha. Fertilizers are applied as basal and it is suggested to place it at a depth of 10 to 15 cm. Foliar application of K is also recommended. Seedlings are susceptible to chloride toxicity; therefore, it is recommended not to place muriate of potash too close to the seed (Anonymous, 2009).

### Growth and Development

Pigeonpea is said to be a drought resistant crop suitable for semi-arid tropics for dry land agriculture. The temperature range in which plant growth and development occur is characterized by base temperature, i.e. the temperature below which the rate of development is zero, an optimum temperature at which the rate of development is most rapid, and a maximum ceiling temperature beyond which development ceases (Summerfield *et al.*, 1991). Base temperature, optimum temperature and maximum temperature for growth has been estimated to be 10°C, 32°C and 45°C, respectively (Carberry *et al.*, 2001). Plant tolerates low (5-10°C) and high (up to 45°C) temperature. Ideal temperature for seedling germination is 29 to 36°C.

### Phenology

Growth and development of pigeonpea is divided into ten phenophases viz., sowing, germination, emergence, end of juvenile stage, floral initiation, flowering, start of grain fill, end of grain fill, maturity, and harvest (Robertson, *et al.*, 2001a).

During germination pigeonpea seeds secrete substance(s) having anti-ethylene like activity (Prakash *et al.*, 2003). The initial two leaves formed at the time of germination are primary leaves, which are simple and opposite. The subsequently formed leaves are pinnately trifoliate. Leaflets are having pulvinous with lanceolate to elliptical shape and acute ends. At a photoperiod of 12 and 16 hours, continuous increase in leaf number on main stem was observed till floral initiation (Turnbull, 1986). A combination of day and night temperature ranging from 16 to 32°C, the rate of appearance of main stem node has been found to be constant having a linear relationship with the daily mean temperature in the range of 20 to 30°C (Turnbull, 1986). The optimum temperature for the rate of node appearance is reported to be close to 32°C (McPherson *et al.*, 1985). The rate of appearance of leaves till maturity has been found to be dependent on plant density, but not on cultivar or the maturity type (Ranganathan *et al.*, 2001). As the plant density increases number of leaves per plant decreases because primary branches growth is suppressed due to inter plant competition. A linear relationship has been reported between



main stem node number and thermal time ( $^{\circ}\text{Cd}$ ) in temperature range between 10 to  $31.5^{\circ}\text{C}$ , which was unaffected by the growth duration and the level of determinacy. It is also calculated that there is appearance of  $0.4 \text{ leaves } ^{\circ}\text{Cd}^{-1}$  at low plant density (4.4 plants/m), and  $0.07 \text{ leaves } ^{\circ}\text{Cd}^{-1}$  at high plant density (Ranganathan *et al.*, 2001). Leaf size in pigeonpea attains about 95% of the maximum in 18-22 days (Rawson and Constable, 1981). There is exponential increase in the leaf size from first trifoliate leaf to higher nodes on the main stem and continues to increase unless it attains the maximum size, after which the size on subsequent nodes decreases (Flower, 1986). Similar pattern has been observed for leaves born on secondary and tertiary branches (Flower, 1986). Comparison of 5 medium-duration and a perennial pigeonpea cultivars, Ranganathan *et al.* (2001) indicated no differences in leaf size ( $\text{area leaf}^{-1}$ ), but when there was no inter-plant competition (low plant density) average leaf size increased. Leaves appeared after flowering initiation were also reported not to attain their potential size because of competition of assimilates between leaves and developing pod (Flower, 1986). In pigeonpea, leaf abscission starts from base of the canopy. The rate of abscission increases after 45 days of full expansion and at flowering less than 10% of the total leaves in this strata of the canopy remain intact (Sanetra, 1998). A sharp decline in leaf area index was observed in pigeonpea after the onset of flowering, even in indeterminate types (Ranganathan *et al.*, 2001; Sheldrake and Narayanan, 1979a).

Leaf size varies in different genotypes, and is influenced by environmental conditions. Leaf expansion is very sensitive to moisture stress, nitrogen deficiency and assimilates supply (Robertson *et al.*, 2001a). In fact, growth habit (shape) of pigeonpea mainly depends upon number of primary and secondary branches and the angle of branches on the stem on which they are born (Remanandan, 1990). In varied maturity group of cultivars of pigeonpea, the rate of leaf production per node has been found to be similar, but plant density influences it significantly by influencing inter-plant competition for minerals, water, light, and assimilates for leaf growth (Ranganathan *et al.*, 2001). In extra-short duration and short-duration pigeonpea genotypes leaf dry matter reaches the maximum at early pod development stage then declines rapidly due to abscission of leaves and remobilization of carbon assimilates to developing seeds, while in medium duration types no such declines occur due to continuous formation of new leaves (Sanetra 1998). Leaf yellowing and abscission starts from bottom to the top and related to the age of the leaf. At harvest, leaves close to the pod bearing top of the plant had survival rate of 75% in extra-short duration and 31% in short-duration types (Sanetra 1998).

In medium duration pigeonpea sown at low plant densities, formation of primary branches starts from the basal main stem node, generally after appearance of 8-10 leaves on main-stem nodes, and leaves on primary



branches appear after development of 17-20 nodes on the main stem (Sheldrake and Narayanan, 1979a). Secondary and tertiary branches are produced when plant density is low, however, at higher plant densities development of secondary and tertiary branches are suppressed.

As compared to other grain legume crops, the juvenile growth in pigeonpea is poor. In the early stage low leaf area development occurs, where as major fraction of dry matter is invested in roots. In late maturing genotypes, it is observed that stem and leaf dry matter, leaf area index (LAI) and crop growth rate (CGR) increase exponentially from 70 days after sowing (DAS). The maximum LAI (13.4-15.5) is achieved at about 140 DAS, and maximum CGR is attained between 196-224 DAS. The maximum light interception takes place at LAI 6-7 (Hughes *et al.*, 1981). Extra-short, short, and medium-duration pigeonpea genotypes may attain LAI up to 3, 4 and 6, respectively (Robertson *et al.*, 2001b). The crop has characteristic of massive stem and abundance foliage production and dry matter in these two parts represent 80% of total dry matter (Shivkumar and Virmani, 1980).

Its roots are deep and wide spreading. They may penetrate up to a depth of 2 m, but the maximum development occurs in upper 60 cm soil profile (Sheldrake and Narayanan, 1979b; Natarajan and Willey, 1980a, b). Depth and spreading of roots depends upon the duration of the crop and its spreading type (Sheldrake and Narayanan, 1979b; Mahta and Dave, 1931).

Generally, flowers are terminal or auxiliary racemes. The raceme form a terminal panicle in indeterminate type and almost corymb shaped bunch in the determinate types, which form group together at the end of branches in late types and distributed along the branches in early, medium and indeterminate types (Sharma and Green, 1980; Singh and Oswalt, 1992). On the branches of indeterminate types, flowering begins at basal nodes and proceeds acropetally; on morphologically determinate types, flowering begins on the apical racemes and proceeds basipetally. In both the types, within the raceme flowering proceeds acropetally, therefore, under normal condition more pods are set from earlier-formed flowers, which are present at the more basal nodes of raceme (Sheldrake and Narayanan, 1979a). Large variations in number of racemes per plant (6-915) have been reported.

### Reproductive Growth

Pigeonpea is a short-day plant and critical day length is about 13 hours (Roy Sharma *et al.*, 1981). Quantitative short-day, day-neutral or nearly-day neutral and intermediate photoperiodic forms have also been identified (Akinola and Whiteman, 1975; Turnbull *et al.*, 1981). However, Mahta and Dave (1931) have reported it to be a qualitative short-day plant. Crop is very sensitive to photoperiod and temperature. Most photo-thermo sensitive traits of crop are plant height, vegetative biomass;



phenology and grain yield (Byth *et al.*, 1981; Whiteman *et al.*, 1985; Chauhan *et al.*, 2002). In short duration pigeonpea lines warm temperature (mean 23.5°C) was found to hasten the time from sowing to flowering and maturity, and between flowering and maturity. Cool temperature (17.8°C) delayed these durations, and the delay was reported to be most pronounced between flowering and maturity (Silim and Omanga, 2001). However, decreased photoperiod (8 hours) or increased in temperature more than 24/16°C delays flowering in the plant (Turnbull *et al.*, 1981). The optimum temperature for rapid flowering are reported to be 24.7°C for short-duration genotypes, 23.8 and 22.2°C for medium duration genotypes and 18.3°C for long duration genotype (Silim, *et al.*, 2007). Short duration genotypes are reported to be last sensitive to photoperiod, while long duration genotypes are extremely photoperiod sensitive.

Flowers are generally yellow in colour, papilionaceous, zygomorphic, clistogamous, and often cross pollinated. Cross pollination ranges from 3-40% (Khan, 1973). In extra-short, short and medium duration pigeonpea genotypes (maturity period 98, 124 and 200 days, respectively), the days to 50% flowering was found to be 52, 69 and 116 days, respectively (Sanetra, *et al.*, 1998). Medium and long duration genotypes flower at the end of rainy season. Pre-mature abscission of flowers is the most serious problem in pigeonpea (Fakir, 1997), and it may reach to about 70-96% (Sheldrake, *et al.*, 1979; Fakir, 1997). Excessive flower drop is one of the major reasons for poor yield in this crop. Genotypic differences with respect to flower drop have been reported (Fakir, 1997). Plants accumulated 10%, 17% and 25% of their total dry matter before flowering in extra-short, short and medium duration genotypes, respectively. When crop entered the reproductive stage, the short-duration types shifts the investment of dry matter from leaves and stems to pods, while medium duration continued to accumulate large amount of dry matter in stem. Leaf dry matter reached a maximum in early pod development and then declined rapidly in extra-short duration and short duration types, while in medium duration types there was no clear decrease as these genotypes continued the formation of new leaves even at late growth stage. As compared to extra short- and short-duration types, the medium duration accumulated a relatively small proportion of dry matter in pods (Sanetra, *et al.*, 1998).

Pods are flat, usually green in colour, sometimes hairy, sometimes streaked or coloured dark purple with 2-9 seeds per pod. Growth of pod is biphasic in nature. First there is increase in size of fruit walls (up to 21-27 days after anthesis) and then the contained seeds. Yadav (1983) observed continuous increase in dry weight of fruit walls up to 28 days of opening of flowers, and then a decline, while dry weight of the contained seeds increased up to maturity (49 days after opening of flowers). Accumulation of dry matter in seeds reported to be very poor up to 21



days of opening of flowers. The nitrogen content in fruit walls increased sharply up to 21 days and then declined, while total nitrogen in seeds started to increase after 14 days of opening of flowers and continued to increase sharply up to 42 days, followed by slight decline. Protein accumulation in pod was found to be slower up to 21 days as only 14% of total protein was deposited during this period, while between 21-42 days nearly 75% of the total protein was deposited, and remaining 8% was deposited between 42 days to maturity. The increase in protein content of seed was accompanied by a simultaneous increase in dry weight from 21-42 days after opening of flowers, while there was reduction in nitrogen content and dry weight of fruit walls after 21 and 28 days, respectively. Decrease in nitrogen content and dry weight of fruit walls and concomitant increase of these parameters in contained seeds was attributed to the translocation of accumulated nitrogen and photosynthates from fruit walls to the contained seeds (Yadav, 1983). Concentration of most of the amino acids in seeds increased from 14- 28 days of opening of flowers and declined sharply during the period of maximum accumulation of storage protein in seeds (21-42 days after opening of flowers). Amino acids valine, isoleucine, cysteine, proline, aspartic acid, serine and threonine were not detected in matured seeds (Yadav, 1983). Four phases of seed development, i.e. lag phase of dry matter accumulation (a phase of cell division; 0-15 days after anthesis), rapid water uptake phase (cell enlargement phase; 9-36 days after anthesis), rapid rate of dry matter accumulation (dry matter accumulation phase; 18-42 days after anthesis), stabilization of dry matter accumulation (maturation phase; 39-54 days after anthesis) have been observed in pigeonpea (Chaudasama and Thakar, 2007a; 2007b). However, overlapping in these phases within the genotype and variations with respect to maturity durations has been observed. Seeds are widely variable in colour, 6-9 mm in diameter and weigh 4-25 g/100 seed (Sheldrake, 1984). Unlike other legume crops, the average weight of earlier and late formed pods, seeds per pod, test weight and nitrogen content of seed did not vary significantly (Sheldrake and Narayanan, 1979a).

### **Radiation-Use Efficiency and Photosynthetic Characteristics**

In extra-short, short and medium duration pigeonpea genotypes, the radiation extension coefficient, i.e. the proportion of radiation intercepted by the crop canopy in relation to leaf area index (LAI) and radiation use efficiency are reported to be 0.53 and 0.9 g MJ<sup>-1</sup>, respectively, which remains almost consistent in genotypes of different maturity group. The ratio of portioning of dry matter between leaf and stem, prior to flowering, was also found to be consistent and varied from 1:1.03 to 1:1.14 in different maturity groups (Robertson *et al.*, 2001a).

Pigeonpea is a C<sub>3</sub> plant. In fully mature leaves, net photosynthetic rate is reported to be around 30  $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$  (Srivastava *et al.*, 2010).



Under waterlogging as well as soil moisture stress conditions, decrease in net photosynthetic rate has been reported (Lopez *et al.*, 1987; Srivastava *et al.*, 2010). Carbon supply may become limiting at high plant population density or low incident radiation (Robertson *et al.*, 2001a). In extra-short, short and medium duration pigeonpea genotypes, proportion of the ratio between root and shoot is reported to be fixed and varies with the phenological stage as 1.00, 0.25, 0.20 and 0.10 at emergence, end of juvenile stage, flowering and at the end of grain fill (Robertson *et al.*, 2001a). Total respiratory losses during vegetative phase in shoot, roots and nodules, account for 65%, 23% and 12%, respectively. During reproductive phase, respiratory losses from roots increases, while that of shoot and nodules decreases. Total respiratory loss, as a proportion of net photosynthesis, remains more or less constant until flowering and pod setting, but increased significantly during seed filling (Rao *et al.*, 2007). Photosynthates supply to nodules and nodule roots increases up to 75 days and 90 days after sowing, respectively (Rao *et al.*, 2007).

### Translocation of Assimilates

In legumes there is remobilization of nitrogen from vegetative parts to the seeds to meet out their high demand as uptake alone can not fulfill the seed requirements (Sinclair and de Wit, 1975). Among extra-short, short and medium duration genotypes, short duration genotypes have been found to be most efficient in remobilization of canopy nitrogen to pod. Percentage of canopy nitrogen mobilized to pods was found to be 39.5, 47.0 and 37.0 in extra-short, short and medium duration genotypes, respectively (Sanetra *et al.*, 1998). In these genotypes, respectively, 60% 40% and 63% of pod nitrogen is reported to be derived from underground plant parts mainly by inorganic nitrogen uptake. It is also suggested that the efficiency to remobilization of the leaf nitrogen to the development of seeds is related to the pattern of leaf abscission. Short duration varieties are reported to remobilize leaf nitrogen more efficiently than extra short and medium duration varieties (Sanetra *et al.*, 1998).

### Drought Resistance and Yielding Ability

Though crop is said to be resistant to drought, but in long duration pigeonpea genotypes, increase in productivity has been observed by supplementary irrigation (Kumar Rao, *et al.*, 2001). Stress tolerance in pigeonpea has been attributed to its greater osmotic ability, which enables plants to tolerate considerable lowering of plant water potential without complete stomatal closure. Osmotic adjustment also enables pigeonpea to maintain physiological processes during water deficit and allows rapid recovery when favourable conditions prevails (Flower and Ludlow, 1986; Lopez *et al.*, 1987; Srivastava *et al.*, 2010).

Development of extra-short duration of pigeonpea genotypes has enabled them to escape the terminal drought, which short and medium



duration types may experience (Nam *et al.*, 1993). Extra-short duration pigeonpea genotypes may experience intermittent stress, as they are dependent on current rainfall, while medium and long duration types may experience intermittent as well as terminal drought (Chauhan *et al.*, 1993). Genotypic differences in drought tolerance in pigeonpea have been reported (Lopez, *et al.*, 1996). Drought stress, imposed at different phenological stages influences yield differently (Nam *et al.*, 2001).

Pigeonpea genotypes differ in growth habit, phenological potential and their relative sensitivity to climatic conditions (Patel *et al.*, 2000). Indeterminate genotypes generally attain higher maximum leaf area index, dry matter production (Rao and Mitra, 1994), but determinate genotypes due to enhanced pod bearing capability and improved harvest index produce more (Narayanan and Sheldrake, 1979). Higher grain yield has also been reported in medium and long duration types than in short duration types (Egbe and Vange, 2008). Variations in yielding potential with respect to genotypes as well as due to variations in environmental conditions have been observed. Genotypic differences in yield potential have mainly been attributed to the differences in the harvest index (Kumar Rao *et al.*, 2001). Seed yield of 2.7 tonnes/ha has been reported in long duration pigeonpea under non-limiting soil moisture condition (Kumar Rao *et al.*, 2001).

In extra-short-duration pigeonpea genotypes, drought imposed during pre-flowering stage did not affect days to 50% flowering, but it affects crop maturity. However, stress during flowering and pod-filling stages hastens crop maturity. Pre-flowering stage reduced total dry matter by 30-50%, while that of flowering stage drought caused about 37% reduction in total dry matter. Flower drop was reported to be more in non-stressed plants than in stressed plants. In extra-short duration pigeonpea lines drought stress imposed at pre-flowering stage reduced grain yield by 11-45%, and at flowering stage reduced it to 40-55%. Drought stress commencing from pre-flowering to flowering or from the flowering to pod-filling have been reported to be more harmful than the stress of the individual stage (Nam *et al.*, 2001).

Work carried out by Plant Physiologists at AICRP (Pigeonpea) Centre at Bangaluru under AICRP using rain out shelters has led to identification of genotypes showing lesser reduction in yield under terminal moisture stress from flowering to maturity.

Productivity of pigeonpea is low. It produces excessive amount of dry matter, which has been reported to be as high as 23 tonnes/ha in some Australian genotypes (Akinola and Whiteman, 1975). At ICRISAT, India, 3-5 tonnes/ha dry matter in early duration, and 6-8 tonnes/ha dry matter in medium duration types has been reported (Sheldrake and Narayanan, 1979a). Nearly 80% of the dry matter is represented by stem and foliage (Shivkumar and Virmani, 1980). Seed yield of the crop ranges between 1-2 tonnes/ha. Under favourable conditions, at ICRISAT, India seed yield



of 1.6-2.5 tonnes/ha has been reported. An exceptionally high yield of 5 tonnes/ha has been reported by Rachie and Roberts (1974). As a result excessive foliage and stem growth, but poor yield, the harvest index (HI) of the crop is very poor, which is reported to vary from 14- 25% (Ariyanayagam, 1975; Sheldrake and Narayanan, 1979a; Roy Sharma *et al.*, 1981). Variation in harvest index across the maturity groups has been reported, as 35%, 32% and 19% for extra-short, short and medium-duration types, respectively (Robertson *et al.*, 2001a).

In Asia, during 1976-2006, pigeonpea has recorded 56 % increase in area (2.76 -4.32 million ha) and 54 % increase in production 2.14-3.29 million tonnes). During these periods, in Africa, there has been 133% increase in area (0.24 million ha-0.56 million ha), and 178% increase in production (0.14 million tonnes - 0.39 million tonnes) (Wikipedia, the free Encyclopedia). The compound growth rate of pigeonpea production in India, between 1949-50 and 2004, had been 0.8%, which is very low (Ahlawat *et al.*, 2005). Besides its sensitivity to various biotic and abiotic stresses, massive foliage, excessive flower drop, and low harvest index are some of the reasons for poor productivity. Conventional plant breeding methods have not been successful in improving pigeonpea productivity because of genetic variation and incompatibility among the wild varieties (Sharma *et al.*, 2006). Discovery of stable genetic male-sterility (Reddy *et al.*, 1978) coupled with its out crossing nature, has opened the possibility for commercial utilization of heterosis in pigeonpea.

### Hybrid Pigeonpea

Hybrid pigeonpea has shown the definite yield advantage over traditional varieties. Efforts have also been made to broaden the genetic base of cultivated germplasm, incorporation of biotic and abiotic stresses and development of cytoplasmic genetic male sterile lines. Wild *Cajanus* species such as *C. scarabaeoides* possesses both physical and antibiosis types of resistance to pod borer and *C. sericeus* and *C. albicans* are rich in protein and tolerant to soil salinity. *C. cajanifolius* can be used for resistance to phytophthora stem blight. Male sterile plants were also isolated from inter specific cross of *C. scarabaeoides* and *C. sericeus* with cultivated species, hence such untapped genes are being utilized for increasing resistance to biotic and abiotic stresses.

The hybridizations has paved the way for enhancing the grain yield potential of pigeonpea, because of partial out crossing and spontaneously arisen genetic male sterility system. Earlier some GMS based hybrids, such as ICPH 8, PPH 4, COH 1, COH 2, AKPH 4104 and AKPM 2022 were released, which have shown yield advantage over the traditional varieties but these hybrids could not become popular. These hybrids seed production of these hybrids is costly and needs manual labour to rogue out the male fertile segregants within female rows after initiation of flowering.

Development of cytoplasmic male sterile line and fertility restorer lines has helped for the exploitation of hybrid vigour for a possible break through in yield potential of pigeonpea, and two stable cytoplasmic male sterile line GT 288A and 67A were developed utilizing cytoplasm of wild species *C. scarabaeoides* and *C. sericeus*. Simultaneous conversion of CMS lines into suitable agronomic backgrounds and identification of fertility restorer lines resulted in experimental hybrids. Hybrid development in pigeonpea has paved the way for enhancing crop productivity. Two stable cytoplasmic sterile lines GT 288A and 67A have been developed using cytoplasm of wild species *Cajanus scarabaeoides* and *C. sericeus*. The first CMS based pigeonpea hybrid, GTH-1 has been released from Gujarat, and it gave 32% higher yield over the best checks. It has white large seeds and matures in 140 days with better yielding potential. Adopting CMS-based hybrid technology, the ICRISAT, India, has developed world's first commercial pigeonpea hybrids, 'Pushkal', having 40% higher yields than the best local varieties. The new hybrid pigeonpea thrives in drought conditions and has greater resistance to diseases than the best varieties. It also has a strong root system that aids greater nitrogen fixation to keep soils fertile. Dr M.S. Swaminathan has compared this breakthrough in developing a hybrid pigeonpea to the development of wheat and rice with dwarfing genes that launched the global Green Revolution for cereals in the 1960s. ICRISAT also intends to come out with 'Bt' chickpea. This is the sincere approaches to enhance quality and productivity of the crop.

Recently release a CMS based hybrid ICPH 2671 has given 28 q/ha grain yields in 2008 (Gowda, 2010). Three new hybrid varieties have been put on trial on farmer's field in collaboration with State Agricultural University of Karnataka, Andhra Pradesh and Maharashtra, and will be available for commercialization for multiplication by the 2010 (Gowda, 2010). These varieties are ideally suitable for dry land and water scarce regions.

## REFERENCES

- Ahlawat, I. P. S.; Gangaiah, B. and Singh, I. P. 2005. Pigeonpea research in India-an over view. *Indian J. Agric. Sci.* **75**: 309-20.
- Akinola, J. O. and Whiteman, P. C., 1975. Agronomic studies on pigeon pea (*Cajanus cajan* (L.) Millsp.). I. Field responses to sowing time. *Australian J. Agric. Sci.* **26**: 43-56.
- Ali, M. 1990. Pigeonpea: Cropping systems. In: *The Pigeonpea*. Nene Y. L., Hall S. D. and Sheila V. K., (Eds). Willingford, UK, CAB International.
- Anonymous. 2009. Mineral nutrition in pigeonpea, March 6, 2009. <http://agropedia.iitk.ac.in>
- Anonymous. 2005a. The Hindu, May 7, 2005
- Anonymous. 2005b. FAOSTAT 2005. <http://faostat.fao.org/database>



- Ariyanayagam, R. P. 1975. Status of research in pigeonpea in Trinidad. *In: Proceedings of International Workshop on Grain Legumes*. ICRISAT, Hyderabad, India, pp. 131-47.
- Byth, D. E.; Wallis, E. S and Saxena, K. B. 1981. Adaptations and breeding strategies for pigeonpea. *In: Proceedings of the International Workshop on Pigeonpea*, 15-19 Dec., 1980. ICRISAT, Patancheru, AP., India. **1**: 450-70
- Carberry, P. S.; Ranganathan, R; Reddy, L. J.; Chauhan, Y. S. and Robertson, M. J. 2001. Predicting growth and development of pigeonpea: Flowering response to photoperiod. *Field Crop Res.* **68**: 151-62.
- Chandra Mohan, J. 1969. A note on the effect of limited irrigation on the yield of pulses. *Madras Agric. J.* **56**: 85-86.
- Chaudasama, R. S. and Thakar, V. S. 2007a. Relationship between endogenous abscissic acid and dry matter accumulation in developing seed and pod of pigeon pea (*Cajanus cajan*). *World J. Agric. Sci.* **3**: 833-42.
- Chaudasama, R. S. and Thakar, V. S. 2007b. Relationship between gibberellic acid and growth parameters in developing seed and pod of pigeon pea. *Brazil J. Plant Physiol.* **19**: 43-51.
- Chauhan, Y. S.; Johansen, C. and Singh, L. 1993. Adaptation of extra-short-duration pigeonpea to rainfed semi-arid condition. *Exp. Agric.* **29**: 233-43.
- Chauhan, Y. S.; Johansen, C.; Moon, Jung-Kyung; Lee, Yoeng-Ho; and Lee, Suk-Ha. 2002. Photoperiod response of extra-short duration pigeonpea lines developed at different latitudes. *Crop Sci.* **42**: 1139-46.
- Egbe, O. M. and Vange, T. 2008. Yield and agronomic characteristics of 30 pigeonpea genotypes at Otobi in Southern Guinea Savanna of Nigeria. *Life Sci. J.* **5**:70-80.
- Fakir, M. S. A. 1997. 'A study of morphophysiological selection criteria related to yield in pigeonpea'. Ph. D. Thesis, Univ. West Indies, Augustine, Trinidad.
- Flower, D. J. 1986. 'The role of osmotic adjustment in the water stressed leaves of pigeonpea (*Cajanus cajan* (L.) Millsp.)'. Ph. D. Thesis, Univ. Queensland, Brisbane, Qld. Australia.
- Flower, D. J. and Ludlow, M. M. 1986. Contribution of osmotic adjustment to the dehydration tolerance of water-stressed pigeonpea (*Cajanus cajan* (L.) Millsp.) leaves. *Plant Cell Environ.* **9**: 33-40.
- Gowda, C. L. L. 2010. More hybrids varieties of tur to hit market. Business Standard. <http://www.CGIAR.org/enews/april> 2010
- Hughes, G.; Keatinge, J. D. H. and Scott, S. P. 1981. Pigeonpea as a dry season crop in Trinidad, West Indies. II Interception and utilization of solar radiation. *Tropical Agric. (Trinidad)*. **58**: 191-99.
- Khan, T. N. 1973. An approach to the breeding of pigeonpea (*Cajanus cajan* (L.) Millsp.); formation of composites. *Euphytica*. **22**: 373-77.

- Kumar Rao, J. V. D. K. 1990. Pigeonpea: nitrogen fixation. *In: The Pigeonpea*. Nene Y. L., Hall S. D. and Sheila V. K., (Eds). C.A.B. International, Wallingford, pp. 233–56.
- Kumar Rao, J. V. D. K. and Dart, P. J. 1987. Nodulation, nitrogen fixation and nitrogen uptake in pigeonpea (*Cajanus cajan* L. Millsp.) of different maturity groups. *Plant Soil*. **99**: 255-66.
- Kumar Rao, J. V. K. D; Johansen, C. and Usha Kiran, M. 2008. Nitrogen requirements at different growth stages of short-duration pigeonpea (*Cajanus cajan* L. Millsp.). *J. Agron. Crop Sci*. **175**: 15-28.
- Kumar Rao, J. V. K. D; Johansen, C., Yoneyam, T.; Tobita, S. and Ito, O. 1996. Estimation of nitrogen fixation by the natural <sup>15</sup>N-abundance technique and nitrogen uptake by pigeonpea genotypes of different maturity groups in an Inceptisol. *J. Agron. Crop Sci*. **177**: 129-38.
- Kumar Rao, J. V. K. D; Johansen, C.; Chauhan, Y. S.; Jain, V. K.; Jain, K. C. and Talwar, H. S. 2001. An analysis of yield variation among long duration pigeonpea genotypes in relation to season, irrigation and plant population. *J. Agric. Sci*. **136**: 291-99.
- Lopez, F. B.; Johansen, C. and Chauhan, Y. S. 1996. Effect of timing of drought stress on phenology, yield and components of short-duration pigeonpea. *J. Agron. Crop Sci*. **177**: 311-20.
- Lopez, F. B.; Setter, T. L. and McDavid, C. R. 1987. Carbon dioxide and light responses of photosynthesis in cowpea and pigeonpea during water deficit and recovery. *Plant Physiol*. **85**: 990-95.
- Mahta D. N. and Dave, B. B. 1931. Studies in *Cajanus indicus*. Memoirs, Department of Agriculture, India (Botanical Series). **19**: 1–25.
- McPherson, H. G. Warrington, I. J., Turnbull, H. I. 1985. The effect of temperature and day length on the rate of development of pigeonpea. *Ann. Bot*. **56**: 597-611.
- Nam, N. H.; Chauhan, Y. S. and Johansen, C. 1993. Comparison of extra short-duration pigeonpea with short season legumes under rainfed condition on an Alfisol. *Exp. Agric*. **29**: 307-16.
- Nam, N. H.; Chauhan, Y. S. and Johansen, C. 2001. Effect of timing of drought stress on growth and grain yield of extra-short-duration pigeonpea lines. *J. Agric. Sci*. **136**: 179-89.
- Narayanan, A. and Sheldrake, A. R. 1979. Pigeonpea (*Cajanus cajan*) as a winter crop in peninsular India. *Exp. Agric*. **15**: 91-95.
- Natarajan, M. and Willey, R. W. 1980a. Sorghum-pigeonpea intercropping and the effect of population density. I. Growth and yield. *J. Agric. Sci. Cambridge*. **95**: 51-58.
- Natarajan, M. and Willey, R. W. 1980b. Sorghum-pigeonpea intercropping and



the effect of population density. II. Resource use. *J. Agric. Sci. Cambridge*. **95**: 59-65.

Patel, N. R.; Mehta, A. N. and Sheikh, A. M. 2000. Radiation absorption, growth and yield of pigeonpea cultivars as influenced by sowing dates. *Exp. Agric.* **36**: 291-301.

Prakash, S.; Koul, S. and Bhalla-Sarin, N. 2003. Germinating pigeonpea (*Cajanus cajan*) seeds secrete factor(s) having antiethylene-like effects. *Physiol. Plant.* **118**: 589-96.

Price, M. L. 1990. Pigeon pea. ECHO Technical Note. ECHO, 17391 Durrance Rd. North Ft. Myer FL 33917, USA. <http://www.echonet.org/>

Rachie, K. O. and Roberts, L. M. 1974. Grain legumes of the low-land tropics. *Adv. Agron.* **26**: 1-132.

Ranganathan, R.; Chauhan, Y. S.; Flower, D. J.; Robertson, M. J.; Sanetra, C. and Silim, S. N. 2001. Predicting growth and development of pigeonpea: Leaf area development. *Field Crop Res.* **69**: 163-72.

Rao, A. S.; Luthra, Y. P.; Sheoran, I. S. and Singh, R. 2007. Partitioning of carbon and nitrogen during growth and development of pigeonpea (*Cajanus cajan* L.). *International J. Bot.* **3**: 85-90.

Rao, L. J. and Mitra, B. N. 1994. Planting pattern of two pigeonpea (*Cajanus cajan*) cultivars when intercropped with groundnut (*Arachis hypogaea*). *J. Agric. Sci.* **122**: 415-25.

Rao, S. C.; Saxena, K. B.; Pachepsky, L. B. and Reddy, V. 2002. Modeling pigeonpea phenology. *International J. Biotrinics.* **31**: 85-100.

Rawson, H. M. and Constable, G. A. 1981. Gas exchange of pigeonpea: a comparison with other crops and a model of carbon production and its distribution within the plant. *In: Proceedings of the International Workshop on Pigeonpea*. Vol.1. 15-19 Dec. 1980. ICRISAT Center. India. ICRISAT, Patancheru, AP. India, pp. 175-90.

Reddy, B. V. S.; Green, J. M. and Bisen, S. S. 1978. Genetic male sterility in pigeonpea. *Crop Sci.* **18**: 362-64.

Rego, T. J. and Nageswara Rao, V. 2000. Long-term effects of grain legumes on rainy-season sorghum productivity in a semi-arid tropical vertisol. *Exp. Agric.* **36**: 205-21.

Remanandan, P. 1990. Pigeonpea: genetic resources. *In: The Pigeonpea*. Nene Y. L., Hall S. D., Sheila V. K., (Eds). CAB International, Wallingford, Oxon, UK, pp. 89-117.

Robertson, M. J.; Carberry, P. S.; Chauhan, Y. S.; Ranganathan, R. and O'Leary, G. J. 2001a. Predicting growth and development of pigeonpea: A simulation model. *Field Crop Res.* **71**: 195-210.

Robertson, M. J.; Slim, S. N.; Chauhan, Y. S. and Ranganathan, R. 2001b.

Predicting growth and development of pigeonpea: Biomass accumulation and partitioning. *Field Crop Res.* **70**: 89-100.

Roy Sharma, R. P.; Thakur, S. C. and Sharma, H. M. 1981. Pigeonpea is a rabi crop in India. *In: Proceedings of the International Workshop on Pigeonpea.* December 1980. ICRISAT, Patancheru, AP, India. **1**: 15-19.

Sanetra C. M. 1998. Characterization of leaf senescence in relation to partitioning and remobilization of dry matter and nitrogen in pigeonpea (*Cajanus cajan* (L.) Millsp.). M. Sc. Thesis, Institute for Agronomy and Animal Production in Tropics, Univ. Goettingen, Germany, pp. 86.

Sanetra, C. M.; Ito, O.; Virmani, S. M. and Vlek, P. L. G. 1998. Remobilization of nitrogen from senescing leaves of pigeonpea (*Cajanus cajan* (L.) Millsp.): Genotypic differences across maturity groups. *J. Exp. Bot.* **49**: 853-62.

Sharma, D. and Green, J. M. 1980. Pigeonpea. *In: Hybridization of Crop Plants.* Ferh W. R., Hadley H. H., (Eds). Madison, WI, USA, pp. 471-81.

Sharma, K. K.; Dreelatha, G. and Dayal, S. 2006. Pigeonpea (*Cajanus cajan* (L.) Millsp.). *Methods Molecular Biol.* **343**: 359-68.

Sheldrake, A. R. 1984. Pigeonpea. *In: The Physiology of Tropical Field Crops.* Goldsworthy P. R. and Fisher N. M., (Eds) Wiley, New York, NY, USA, pp. 385-417.

Sheldrake, A. R. and Narayanan, A. 1979a. Comparisons of earlier- and later-formed pods of pigeonpeas (*Cajanus cajan*). *Annals Botany.* **43**: 459-66.

Sheldrake, A. R. and Narayanan, A. 1979b. Growth, development and nutrient uptake in pigeonpea. *J. Agric. Sci.* **92**: 513-26.

Sheldrake, A. R.; Narayanan, A. and Venkataratnam, N. 1979. Effect of flower removal on seed yield of pigeonpea (*Cajanus cajan*). *Annals. Applied Biol.* **73**: 43-46.

Shivkumar, M. R. K. and Virmani, S. 1979. Simulation model in yield predictions under water stress and unstressed condition. *Exp. Agric.* **15**: 377-83.

Shivkumar, M. V. K. and Virmani, S. M. 1980. Growth and resource use of maize, pigeonpea and maize/pigeonpea intercrop in an operational research watershed. *Exp. Agric.* **16**: 377-86.

Silim, S. N. and Omanga, P. A. 2001. The response of short-duration pigeonpea lines to variation in temperature under field conditions in Kenya. *Field Crop Res.* **72**: 97-108.

Silim, S. N.; Gwataa, E. T.; Coeb, R. and Omanga, P. A. 2007. Response of pigeonpea genotypes of different maturity duration to temperature and photoperiod in Kenya. *African Crop Sci. J.* **15**: 73-81.

Sinclair, T. R. and de Wit, C. T. 1975. Photosynthate and nitrogen requirements for seed production by various crops. *Science.* **189**: 565-67.



Singh, F. and Oswalt, D. L. 1992. Pigeonpea botany and production practices. Skill Development Series No. 9. ICRISAT, Patancheru, India, pp. 5-12.

Srivastava, J. P.; Singh, P.; Singh, V. P. and Bansal, R. 2010. Effect of waterlogging on carbon exchange rate, stomatal conductance and mineral nutrient status in maize and pigeonpea. *Plant Stress*. **4** (Special Issue): 94-95.

Summerfield, R. J.; Lawn, R. J.; Roberts, E. H. and Ellis, R. H. 1991. Towards the reliable prediction of time of flowering in six annual crops. I The development of simple models for fluctuating field environments. *Exp. Agric.* **27**: 11-31.

Turnbull, L. V. 1986. The role of photoperiod and temperature in early vegetative growth and floral development in selected lines of pigeonpea (*Cajanus cajan* L. Millsp.). Ph. D. Thesis, Univ. Queensland, Australia.

Turnbull, L. V.; Whiteman, P. C. and Byth, D. E. 1981. The influence of temperature and photoperiod on floral development of early flowering pigeonpea. In: *Proceedings of the International Workshop on Pigeonpea*, December 15-19, 2008. ICRISAT, Patancheru, Hyderabad India. **1**: 217-23.

van der Maesen L. J. G. 1980. India is the native home of the pigeonpea. Liber gratulatorius in honorem HCD de Wit, Misc. Paper 19, Landbouwhogeschool Wageningen, the Netherlands, pp. 257-262.

Vavilov, N. I. 1951. The origin, variation, immunity and breeding of cultivated plants. Translated by K. Start. *Chron. Bot.* **13**: 1-366

Whiteman, E. S.; Byth, D. E.; Wallis, E. S. 1985. Pigeonpea (*Cajanus cajan* (L.) Millsp.). In: *Grain Legume Crops*. Summerfield R. J. and Ellis R. H., (Eds). Collins Professional and Technical Books, London, UK, pp. 658-98.

Wikipedia, the free Encyclopedia. [http://en.wikipedia.org/wiki/Pigeon\\_pea](http://en.wikipedia.org/wiki/Pigeon_pea)

Yadav, S. P. 1983. Amino acid composition of developing pigeonpea (*Cajanus cajan*) seeds. *J. Agric. Food Chem.* **31**: 1360-62. ●

## CHAPTER 10

# Physiology of MULLaRP

### MUNGBEAN

**M**ungbean [*Vigna radiata* (L.) Wilczek] belongs to family Fabaceae. It is a grain legume adapted to tropical and subtropical conditions. Mungbean is also known as green-gram, *mung*, *mongo*, *moong*, *moog*, *mash bean*, *munggo* or *monggo*, golden gram and green soya. The split seed is called as *moong dal*. When cooked with husk, it is green, and with out husk it is yellow. Earlier it was known as *Phaseolus aureus* or *Phaseolus radiata*. (Mung bean. [http://en.wikipedia.org/wiki/Mung\\_bean](http://en.wikipedia.org/wiki/Mung_bean)). It a native of Indian sub-continent (India, Pakistan and Bangladesh). In India, it is grown since ancient time. It is widely grown in India (28.87 m ha), Pakistan (2.03 m ha) and Bangladesh (0.005 m ha), Sri Lanka (0.033 m ha), Myanmar (0.65 m ha), Indonesia (0.324 m ha), Thailand (0.289 m ha), Phillipines (0.039 m ha), China (0.772 m ha), Australia (0.04 m ha), and USA (0.05 m ha) (Winburger, 2003). It is also cultivated in Africa. In United States, its cultivation started since 1835. Besides its use as '*dal*', seeds are also fermented or milled and ground into flour to make products like soups, porridge, confections, curries and alcoholic beverages (Lambrides and Godwin, 2007).

Mungbean is most important grain legume in Thailand and Philippines, second most important in Sri Lanka, and third in India (Fery, 2002). In most of the records mung bean and urd bean productions are given together. About 90% of world production comes from Asia and India is the largest producer of mungbean accounting for more than 50% of world production (Lawn and Ahn, 1985; Vijaylakshmi *et al.*, 2003). During 1980 mung bean production in India was 10,000 tonnes, which increased to 59,899 tonnes in 2006 (Ministry of Agriculture, Forest and Fisheries, 2007). Seed yield of the crop in India is 323 kg/ha, which is much lower than the potential yield of 3000 kg/ha (De Costa *et al.*, 1999). In addition to its suitability for various cropping systems, mungbean can also be intercropped in fields of sugarcane, pigeonpea, mint as well as fruit orchards and poplar plantations, which may provide an additional yield of 0.7-1.0 tonnes/ha without adversely influencing the yield of main crop (Shanmugasundaram *et al.*, 2004).



NUTRITIONAL COMPOSITION OF MUNGBEAN SEED

Sprouted mungbean seeds are consumed as salad. Seeds are easily digestible, therefore, preferred over animal protein. Though seeds contain factors associated with flatulence (raffinose, stachyose and verbascose) in human beings, but these are soluble in water and can easily be removed either by adequate pre soaking, germination or fermentation (Lambrides and Godwin, 2007). Mungbean sprouts are a source of phytoestrogens (cancer protecting agent in animals; Adrian *et al.*, 1994) with high level of estrogenic activity (Stephen *et al.*, 2003). Green pods are occasionally used as vegetables (Lawn, 1995). Chemical composition and nutritive value of dry seeds of mungbean are given in Table 1.

**Table 1.** Chemical composition and nutritive value of dry mungbean seeds

Constituent		Amount per 100 g
Carbohydrates	Total	62.62 g
	Sugar	6.60 g
	Dietary fiber	16.30 g
Fat		1.15 g
Protein		23.86 g
Vitamin C		4.8 mg
Calcium		132.0 mg
Magnesium		186.0 mg
Phosphorus		367.0 mg
Potassium		1246.0 mg
Sodium		15.0 mg
Energy		1450.0 kJ

Source: USDA nutrient database Cited: [http://en.wikipedia.org/wiki/Mung\\_bean](http://en.wikipedia.org/wiki/Mung_bean)

Though upon boiling the nutritive value of mungbean seeds decreased, but their digestibility is improved. Mungbean is used primarily as food; extensive research work is being done on seed quality traits (Imrie, 1983). Chemical composition and nutritive value of boiled mungbean seeds is depicted in Table 2.

**Table 2.** Chemical composition and nutritive value of boiled mungbean seeds

Constituent	Boiled seeds per 100 g
Energy	105 Kcal
Carbohydrates	19.15 g
Sugar	2.00 g
Dietary fiber	7.60 g

Constituent	Boiled seeds per 100 g
Fat	0.38 g
Protein	7.02 g
Vitamin C	1.00 mg (2%)
Calcium	27.00 mg (3%)
Magnesium	0.29 mg (0%)
Phosphorus	99.00 mg (14%)
Potassium	266.00 mg (6%)
Sodium	2.00 mg (0%)

Source: USDA nutrient database Cited: [http://en.wikipedia.org/wiki/Mung\\_bean](http://en.wikipedia.org/wiki/Mung_bean)

Crop Phenology

It is a short duration crop and maturity varies from 55-110 days. Genotypic differences with respect to phenological, physiological and yields forming traits are large, and keeping these parameters in view, Bhattacharya and Vijaylakshmi (2005) grouped them into VIII clusters. A genotype, HUM 16, with 55 days maturity has been developed at the Institute of Agricultural Sciences, Banaras Hindu University, Varanasi (Singh, M.N., Personal Communication). It has uniqueness that no other pulse crop matures in 60-65 days (IIPR, 2009). Plants are generally branched with erect or sub-erect habit. Plant height varies from 0.30-1.25m, which depends upon genotype and agro-ecological conditions. Early maturing genotypes are generally short in height (38-50 cm). Leaves are trifoliate. Flowers are pale yellow and papilionaceous, born in clusters of 12-15 near the top and are self pollinated. Flowering takes place in flushes. When conditions are favourable, even three flushes of flowering may occur. In mungbean, therefore, pod maturity is not synchronous (Yeates *et al.*, 2000), and because of this harvesting is a problem, as it requires manual picking of mature pods. Varieties with synchronous flowering have been developed. With the onset of reproductive growth, vegetative growth of the crop declines. Pods are yellowish-brown to black in colour and contain 10-15 seeds per pod (Oplinger *et al.*, 1990). Seeds are green in colour, but it may vary greatly with the variation in the colour of the testa and presence or absence of texture layer. Texture layer is a secretion from the epidermis of the testa and gives dull or buff appearance when present (Watt *et al.*, 1977). In variety ‘Sona’ seeds are yellow in colour (Katiyar *et al.*, 1999). Generally test weight (100 seed weight) varies between 3-5 g, but genotypes with larger test weight (more than 5 g per 100 seed) are also available (Prasad and Srivastava, 1999; Singh, 1999; Katiyar *et al.*, 1999).



## Rooting and Nitrogen Fixation

Mungbean has tap root system. Under normal condition root water extraction efficiency is higher in the top 0-60 cm soil layer, while under soil moisture stress condition it is more from 60-100 cm soil profile. Roots bear nodules harbouring *Rhizobium* and, hence, are able to fix atmospheric nitrogen. It is estimated to fix 30-40 kg nitrogen per ha (IIPR, 2009). If the field is already inoculated with proper *Rhizobium* strain, there is no need of application of nitrogenous fertilizers; however, 12-16% increment in yield has been reported in extra short duration mungbean genotype SML668, when seeds are inoculated with *Rhizobium* or *Rhizobium* in association with phosphorous solubilizing bacteria (PSB) and plant growth promoting *Rhizobacteria* (PGPR) (Sharma *et al.*, 2007).

On co-inoculation of mungbean seeds with *Pseudomonas* strain MRS-13, MRS-16 *Bradyrhizobium* sp. (*Vigna*) strain-24, there has been a significant increase in nodule weight, plant weight and total N in plants as compared to those which were inoculated with *Bradyrhizobium* strain S-24 only (Sindhu *et al.*, 1999). Ray and Dalei (1998) observed significant increase in mungbean yield when inoculated with *Rhizobium* + mycorrhiza as compared to that when inoculated with mycorrhiza or *Rhizobium* alone (Panwar and Thakur, 1994; Thakur and Panwar, 1995; Jain *et al.*, 2007). Nodulation, nodule number and seed yield increased in mungbean when inoculated with *Rhizobium* + 25 kg urea ha<sup>-1</sup> (Patra and Bharttacharya, 1997).

Remobilization of nitrogen from vegetative parts to pods occurs immediately after they begin to develop, and the quantity may vary from 25-70% depending upon the nitrogen level of the soil. The remobilization of nitrogen to pods is less in nitrogen rich soil grown plants (Weaver and Miller, 1986). Under soil water deficit condition nitrogen fixation is affected more than the biomass accumulation (De Costa *et al.*, 1999).

## Nutrient Requirement

Crop requires phosphorous, potassium and certain micronutrients at level similar to many other field beans as per nutrient status of the field. For soils of moderate fertility 12.5 kg N and 40 kg P<sub>2</sub>O<sub>5</sub>/ha is recommended as a basal dressing. K application is suggested after soil testing. In case recommended dose of N and P is given to wheat or potatoes, then summer mungbean can be grown without fertilizer (Shanmugasundaram *et al.*, 2004). Murtaza *et al.* (1999) observed enhancement in mungbean productivity by application of nitrogen up to 40 kg/ha, however, higher levels of nitrogen reduced yield. The crop improves soil fertility not only through nitrogen fixation, but also by adding organic carbon to soil (Meelu *et al.*, 1994). Treatment with K-biofertilizer is reported to mitigate the effect of drought stress in the crop (Tawfik, 2008).

## Growth and Development

Though it is adapted to tropical and sub-tropical climates and short days hasten flowering, but can be grown to latitudes as higher as 40°, if the mean daily temperature is more than 15°C and area is frost free from planting to maturity (Imrie, 1996). It is planted in the beginning of monsoon (*kharif*). With the development of short duration (60 days) genotypes with synchronous maturity, it is possible to grow mungbean during spring/summer after wheat as a catch crop in rice-wheat cropping system in Indo-Gangetic Plains of India (Sekhon, *et al.*, 2007). Genotype, photo-period and temperature all interact to determine relative earliness to flower (Summerfield and Lawn, 1988). It is a quantitative short day plant, but day neutral genotypes are also reported. Time to flowering of mung bean crops varies appreciably depending on the genotype, and the day lengths and temperatures prevailing during the period after sowing (Imrie and Lawn, 1990). Large numbers of flowers are formed at each reproductive node, but most of them abscise and only few develop fruits.

Plant growth is slow up to 15 days after sowing. The maximum dry matter accumulation and leaf area is achieved between 30-60 days after sowing. The maximum leaf area has been recorded during peak flowering and pod development phase (Prasad and Srivastava, 1999; Pawar and Bhatia, 1980). In mungbean leaf area index of 2-4 is considered to be optimal for interception of maximum light radiation, therefore, density of the plant as well as density of foliage, both affect the crop productivity (Kuo, 1998). Crop growth rate attains the maximum value during flowering (Kuo, 1998). Genotypic differences were recorded with respect to relative growth rate (RGR), net assimilation rate (NAR), and leaf area ratio (LAR). RGR and NAR are reported to be the maximum during 15-30 days, while LAR between 45-60 days after sowing (Prasad and Srivastava, 1999; Chandra *et al.*, 1977). Under field condition in India it has been reported that weight of pod or seed is positively correlated with the leaf area at the node subtending the pod (Savithri *et al.*, 1978).

In wild genotypes photo-thermal environment is found to influence leaf growth, total dry matter production and seed yield, through effect of temperature on growth and indirectly through effect on phenology. Leaf production, leaf expansion and leaf area are found to be sensitive to temperature. Total dry matter production is found to be positively related to total growth duration and harvest index negatively correlated to the duration from sowing to flowering. Seed yield is found to be related positively to the duration of reproductive growth (Rebetzke, and Lawn, 2006). Positive correlation has also been reported between dry matter per plant and seed weight per plant (Singh, 1999). Significant and positive correlations are reported between specific leaf weight (SLW), RuBPCase activity, harvest index (HI) and seed yield in mungbean. It is suggested that for higher productivity genotypes with higher SLW, higher HI and increased RuBPCase activity should be selected (Kuo *et al.*, 1980).



Growth of pod is bi-phasic in nature. Though growth period of fruit walls and seeds varied in genotypes of different maturity groups, but generally fruit walls attains maximum dry weight between 9-11 days after anthesis, but the contained seeds attain maximum dry weight between 19-21 days after maturity. Longer period of seed growth is associated with larger seed size (Hamid *et al.*, 1995). At early stages of development crude protein constitutes about one-third of dry weight, which decreases to about one-quarter at maturity. The total sulphur, which is mainly present as a constituent of the sulphur amino-acids in mature seeds did not change much in mung bean. Storage protein accumulation is reported to be very rapid between 10 and 14 days after flowering ( $10.4\% \text{ day}^{-1}$ ). Thereafter, protein accumulation declines slightly and gradually approaches zero at the time of seed maturity. The sulphur-to-nitrogen ratio gradually increases with maximum values in the mature seeds (Awolumate, 2006). With the advancement in the seed development, the contents of starch increases, while its level in the branch of inflorescence and fruit walls declines after 10 days after flowering (Chopra *et al.*, 2005b). In the branch of inflorescence and fruit walls, the activities of sucrose metabolizing enzymes, viz. acid and alkaline invertase, sucrose synthase and sucrose phosphate synthase are reported to be higher during 5–10 days after flowering, while in seed the maximum activities of these enzymes are reported at the time of maximum seed filling stage (10–20 days after flowering). A high activity of sucrose synthase at the time of rapid seed filling has been attributed to its high sink strength. It is also observed that branch of inflorescence and fruit walls had higher activities of phosphoenol-pyruvate carboxylase (PEP-carboxylase), while in seeds the activity of this enzyme is less. It is suggested that high activity of PEP-carboxylase is an indicative of the involvement of the fruiting structure (fruit walls) for recapturing seed respired  $\text{CO}_2$ . High activities of isocitrate dehydrogenase and malic enzyme in the seed at the time of rapid seed filling has also been reported, and these enzymes are probably involved to provide NADPH and carbon skeletons required for the synthesis of various seed reserves (Chopra *et al.*, 2000). Remobilization of dry matter from fruit walls to contained seeds has not been observed (Hamid *et al.*, 1995).

### Effect of Drought

Growth and development, yield and yield attributes of the crop are affected by drought (Tawfik, 2008). In summer mungbean drought causes reduction in leaf water status, rate of photosynthesis, and alters partitioning of dry matter in different plant parts (Kumar and Sharma, 2009). Photosynthetic rate is observed not to be limiting yield, but its partitioning is affected by leaf relative water content (RWC), thus affecting the yield. Genotypes with higher leaf RWC yielded higher (Kumar and Sharma, 2009). Under water stress plant height, yield, pod number per plant and number of seeds per pod are reduced (Sadeghipour, 2008; Haqqani and Pandey, 1994), while seed protein content is increased



(Sadeghipour, 2009). Water stress at pod filling stage reduces test weight (Sadeghipour, 2008). Drought at reproductive growth phase affects yield most severely than the stress of any other stage (Thomas *et al.*, 2004). Flowering (from appearance of first flower to 75% pod initiation) and pod filling (from 75% pod initiation to maturity) stages have been described as most critical to water stress, as leaf area index during these phases are maximum. Stress of flowering and pod filling stages reduces pod initiation and pod growth rate and, thus, decreases harvest index. Water stress of vegetative, flowering or pod filling stages decreases photosynthesis and consequently, the radiation use efficiency of the crop (De Costa *et al.*, 1999). Defoliation experiment at different canopy strata has indicated that the removal of lower leaves (25% defoliation) enhances seed yield. The remobilization of nitrogen from the older leaves is increased towards active sink (pods) during senescence (Panwar *et al.*, 1988).

Increased stomatal resistance and the quantities of soluble sugars, proline, glycine betaine and abscisic acid have also been reported in plants under water deficit condition (Tawfik, 2008).

After physiological maturity, combination of high temperature and humidity and periods of wetting and drying causes development of hard-seededness (Williams, 1989; Kumari and Dahiya, 1981). Very few genes are reported to be responsible for hard-seededness in mungbean (Lambrides, 1996).

Growth and yield in mungbean respond positively to elevated CO<sub>2</sub> concentration. Elevated CO<sub>2</sub> level also alters fatty acid composition and significantly improves the nutritional benefit of mungbean seeds, as the percentage of palmitic and Omega 6 fatty acids are decreased and relative proportion of Omega 3 fatty acids are increased (Ziska and Blowsky, 2007).

### Yield and Yield Attributes

Genotypic differences exist with respect to dry matter (160-770 g m<sup>2</sup>) production (Sadeghipour, 2009; Pawar and Bhatia, 1980). Early genotypes produce lesser amount of total dry matter than the late genotypes. Generally harvest index ranges between 20-45% (Kuo, 1998), but variations have been reported from 12% to 52% (Sadeghipour, 2009; Prasad and Srivastava, 1999; Pawar and Bhatia, 1980). Important yield components in mungbean are plants per unit area, pods per plant, seeds per plant, and test weight.

### Constraints Limiting Yield

Major causes of low productivity in this crop are low and erratic rainfall, greater intensity of diseases and insects (thrips, pod borers, mungbean yellow mosaic virus, cercospora leaf spot, powdery mildew and pod rot) and sowing of unproductive traditional cultivars (Shanmugasundaram *et al.*, 2004). Pod maturity in mungbean is not



uniform as flowering occurs for an extended duration in flushes. Seed yield from various flushes varies depending upon genotype (Hamid *et al.*, 1995). Uneven pod maturity and maturation leads to low yield potential and poor harvest index (Egli and Bruening, 2002; Bushby and Lawn, 1992), therefore, it is suggested that synchronous maturity would lead to higher harvest index as well as seed yield. Principal factor limiting yield in mungbean are low rate of dry matter production before anthesis and during pod development (Kuo, *et al.*, 1978). It is observed that the time of initiation of the component and rate of growth of the component between time of initiation and harvest, are the major determinant of actual size of yield component (Kuo, 1998). Inverse effect of seed yield due to high leafiness and asynchronous flowering has been reported (Bisht *et al.*, 2005; 1998).

For spring/summer mungbean, it is suggested that an ideal mungbean plant type should have early synchronous maturity, long pods with bold shining seeds and moderate plant height bearing pods at top in the branches, besides having resistance to mungbean yellow mosaic virus (MYMV). Drooping pods with thick fruit walls are desirable as they are less affected by rains and less prone to shattering at maturity (Bains *et al.*, 2007). Efficient remobilization of pre-anthesis photosynthates as well as of current photosynthates during pod growth, are the desirable characters for high yield (Clifford, 1979).

## URD BEAN

Urd bean [*Vigna mungo* (L.) Hepper], also known as *urad dal*, *udad dal*, urd bean, urid, black matpe bean, black gram, black lentil, *maas* in Nepal, and *dâu den* in Vietnam. It is primarily cultivated in southern Asia. It belongs to family Fabaceae, sub family Faboideae, and tribe Phaseoleae. Along with mung bean it was initially placed in genus *Phaseolus*, but has been transferred to genus *Vigna*. It is thought that urd bean is the more recent derivation than mung bean (Lawn and Ahn, 1985).

Urd bean originated in India and from here it has been introduced in other tropical countries. Besides India, other urd bean growing countries are Myanmar, Bangladesh, Pakistan, and Thailand. Crop is also cultivated in Africa, particularly in Gabon, Kenya, Uganda, Tanzania, South Africa and Mauritius. Urd bean is an annual crop with erect, sub-erect or trailing plant type and semi indeterminate growth habit. Immature beans are boiled and eaten. Most urd bean varieties produce black coloured seeds. Mature seeds are consumed as such or used after splitting as *dal*. Seeds are also ground into flour, which is extensively used in southern part of India for making various food preparations viz., *vada*, *idli*, *dosa* and *papadum*. Urd bean flour, when mixed with water forms sticky paste. Urd bean preparations are also very popular in Punjab and western parts of Uttar Pradesh, and in Pakistan. In Punjab urd *dal* preparation is popularly known

as *maas*. (*Vigna mungo*. [http://en.wikipedia.org/wiki/Urad\\_%28bean%29](http://en.wikipedia.org/wiki/Urad_%28bean%29)). It is cultivated as a fodder crop, particularly in USA and Australia. Being a leguminous crop it is also grown for green manuring. It is also cultivated as a cover crop.

NUTRITIONAL COMPOSITION OF SEED

The nutritional composition of per 100 g of edible portions is given in Table 3. Seeds also contain lysine 415 mg, phenyl alanine 365 mg threonine 217 mg, valine 315 mg, leucine 518 mg and tryptophan 65 mg per 100 g edible part of the seeds (Hytowitz and Mathews, 1986).

Table 3. Nutritional composition of urd bean seeds

Component	Value (per 100 g of edible portion)
Water	8.60 g
Energy	1470.00 k J
Protein	25.10 g
Carbohydrate	61.00 g
Crude fibre	4.40 g
Ca	196.00 mg
Mg	260.00 mg
p	575.00 mg
Fe	6.80 mg
Zn	3.10 mg
Vitamins A	114.00 IU
Thiamine	0.36 mg
Riboflavin	0.28 mg
Niacin	1.80 mg
Folate	628.00 µg
Ascorbic acid	4.80 mg

Source: Jansen, 2006

India is the major producer as well as consumer of urd bean where it is cultivated in about 3 m ha area with an annual production of about 1.3 million tonnes In Thailand, Sri Lanka and Pakistan annual urd bean productions are 90,000, 57, 000 and 28.000 tonnes, respectively (Jansen, 2006).

Nitrogen Fixation

In urd bean plant nitrogen content is observed to be positively correlated with nodule number per plant, nodule fresh and dry weights, NR-activity and leghaemoglobin content, and negatively correlated with carbohydrate concentration in plant (Mathur *et al.*, 1998). Significant



genotypic differences are observed in the performance of urd bean cultivars inoculated with *Rhizobium* strain urd-9. It is also observed that light induces more (large and pink coloured) nodules with higher amounts of leghaemoglobin in this crop (Saran, 1995).

### Growth Condition

Urd bean can be grown under extreme environmental conditions viz., high temperature, low rain fall and poor soil fertility, with low inputs, therefore, it easily fits in various cropping systems (Lawn and Ahn, 1985). In India it is sown in summer as well as in monsoon seasons, and cultivated up to 1800 m altitude in areas where average temperature is 25-35°C and annual rain fall is about 600-1000 mm. In summer it can be grown in areas where irrigation facilities are available. It is also intercropped with pigeonpea, sorghum, sesame, sugar cane, and groundnut. In India monsoon sown crop is not irrigated. Crop is also supplied with minimal inputs, such as fertilizers

Positive correlation has been reported between dry matter production and yield in urd bean (Snyder and Carlson, 1984). Photosynthetic rate in variety T 9 of urd bean is reported to be 11.79 mg CO<sub>2</sub> dm<sup>-2</sup> h<sup>-1</sup> (Ignacimuthu and Babu, 1987). Partial defoliation during vegetative and/or reproductive phases results in reduction in dry matter production, leaf/plant weight ratio, crop growth rate and yield, but increase in net assimilation rate. Reduction in yield due to defoliation has been reported to be mainly due to reduced pod number per plant, and some times due to reduced seed number per pod and decreased test weight (Pandey and Singh, 1981)

Urd bean plants are tolerant to drought but very susceptible to frost. Prolonged cloudy weather also affects plant growth and development and crop yield adversely. Harvesting is done when pods are still green. When pods dry, shattering is the major problem.

High temperature in association with high humidity and alternate wetting and drying after physiological maturity of the seeds results in the development of hard-seededness in urd bean (Tomar and Kumari, 1991)

Attempts are being made to develop early maturing (60-90 days maturity period), short stratured (30 cm plant height) plants with determinate growth habit. Crop is highly susceptible to mung bean yellow mosaic virus (MYMV), *Cercospora* leaf spot, web blight, and powdery mildew. It is also heavily attacked by white fly and thrips; therefore, it is very essential to consider these aspects while developing a suitable plant type for a given agroclimatic condition (Jansen, 2006).

## LENTIL

Lentil (*Lens culinaris* Medikus) belongs to family Fabaceae, sub family Faboideae and tribe Viciaeae. It is a pulse (grain legume), and commonly known as *masoor* or *masser* in India. It is also known as *adas* (Arabic), *mercimek* (Turkey), *messer* (Ethopia), *heramame* (Japanese), *mangu* or *margu* (Persian), *masura*, *renuka*, *mangalaya* (Sanskrit) (Sandhu and Singh, 2007).

Lentil is probably the first agricultural crop grown more than 8,500 years ago. It is believed to be the native of South Western Asia and Northern Syria. Archeological evidences indicate its cultivation as early as 6,000 B.C. Lentil seeds have been found in Egyptian tombs dating back to 2,400 B.C. During the Neolithic period it spread to Greece and Bulgaria and during the Bronze Age to the Near East and Mediterranean (Lentils. <http://www.recipes4us.co.uk/specials%20and%20holidays/Lentils%20Origin%20Uses%20Recipes.htm>). It is mainly cultivated in India, Bangladesh, Pakistan, Egypt, Greece, Italy, countries in the Mediterranean region and North America. It is also cultivated in Atlantic coast of Spain and Morocco. There are a number of wild lentils, but *L. orientalis* is considered as the progenitor of cultivated lentil (Sandhu and Singh, 2007). It was introduced into the new world by Spanish and Portuguese in the beginning of 16<sup>th</sup> century, but in USA it was not introduced till First World War (Introduction: Lentils. <<http://www.icarda.org/Publications/Cook/Lentil/Lentil.html>>).

Globally lentil is cultivated in all continents except Antarctica in 4 million ha area including more than 40 countries. As per FAO estimate during calendar year 2007, total lentil production was 3.874 million tonnes and the major producing countries were India (36%), Canada (17%) and Turkey (15%). Other countries viz., China, Syria, Nepal, United States, Australia, Bangladesh and Iran also contribute significantly to world lentil production (FAO: Economic and Social Department: The Statistical Division). Its production as well as consumption is the maximum in India. Canada is the largest exporter of lentil. Globally lentil productivity was only 560 kg ha<sup>-1</sup> during 1961-1963, but reached to 950 kg ha<sup>-1</sup> by 2004-2006, which is still lower as compared to other crops because of the limited yield potential of landraces of lentil and their vulnerability to an array of stresses (Erskine *et al.*, 2009).

Lentil is a staple food of the Near East and India. It is also used in soups, stews, casseroles and salad dishes. Under excessive dry condition of production seed coat becomes hard and such seeds are difficult to cook. On the basis of seed size there are two types of lentil, the large seeded, macrosperma and the Persian microsperma, which has small to medium sized seeds. There are many varieties with in these two groups (Lentils. <http://www.recipes4us.co.uk/specials%20and%20holidays/Lentils%20Origin%20Uses%20Recipes.htm>). Straw as well as poor grade seeds are also used as cattle feed. The crop can also be used as a green manure.



A Canadian variety, Indianhead, has been found to provide about 20 kg N per ha (*Lens culinaris* Medik. <http://www.hort.purdue.edu/newcrop/afcm/lentil.html>). Lentil is an important pulse for crop intensification in West Asia and diversification in South Asia (Sarker *et al.*, 2004).

NUTRITIONAL COMPOSITION OF SEED

Lentil seeds are rich in protein (22-35%). After soybean and hemp, it ranks third in seed protein content. It is also rich in iron, calcium and phosphorus. Sprouted lentils are good source of vitamin C (Introduction: Lentils. <http://www.icarda.org/Publications/Cooks/Lentil/Lentil.html>). Folic acid is an important nutrient found in lentils. In fact lentil provides more folic acid than any other unfortified food (Lentil Facts & Lore. <http://www.lentilfest.com/DrawOnePage.aspx?PageID=6>). Seeds are also rich in essential amino acid, isoleucine and lysine, but deficient in methionine and cystine. The nutritive value of seeds increases with germination (Vidal-Valverde and Frias, 1992). Lentil seeds also contain cholesterol lowering fibers, and help in managing blood sugar disorder. Its higher fiber content prevents blood sugar level from rising rapidly after the meal. Seeds are excellent source of molybdenum and a very good source of manganese. The nutritive composition varies widely depending upon cultivar, growth conditions and agricultural practices (Adsule *et al.*, 1989). Protein digestibility is affected by the presence of trypsin inhibitor compounds, which inhibit enzyme trypsin (Liener and Kakade, 1980). The nutritive value of mature seed is given in Table 4. However, after cooking seeds the availability of minerals is improved as given in Table 5.

**Table 4.** The chemical composition and nutritive value of lentil seeds

Parameter	Content per 100 g seed
Energy	1,477.00 kJ
Carbohydrates	60.00 g
Soluble sugars	2.00 g
Dietary fiber	31.00 g
Fat	1.00 g
Protein	26.00 g
Thiamine (vitamin B1)	0.86 mg
Iron	7.50 mg

Source: Wikipedia. The Free Encyclopedia <http://en.wikipedia.org/wiki/Lentil>

**Table 5.** Chemical composition and nutritive value of cooked lentil seeds. Values in parenthesis indicate percentage of total

Parameter	Value per 100 g
Energy	229.68 kcal
Molybdenum	148.50 (198.0%)
Folate	357.98 mcg (89.5%)
Dietary fibre	15.64 g (62.6%)
Tryptophan	0.16 g (50.0%)
Manganese	0.98 mg (49.0%)
Iron	6.59 mg (36.6%)
Protein	17.86 g (35.7%)
Phosphorus	356.40 mg (35.6%)
Copper	0.50 mg (25.0%)
Vitamin B1	0.33 mg (22.0%)
Potassium	730.06 mg (20.9%)

Source: Wikipedia. The Free Encyclopedia <http://en.wikipedia.org/wiki/Lentil>

**Plant Morphology**

It is a short stratured, annual, bushy, erect, semi-erect or spreading, branched and self pollinated crop. Plant is 15-75 cm tall. It is suitable for cultivation in tropical, sub-tropical and high altitude tropical regions of the world (Muehlbauer *et al.*, 1995). Cool growing season, and sufficient moisture and fertility results in taller plants. Leaves are alternate, compound with 4-8 pairs of leaflets. Upper leaflets are converted into tendrils or bristles. The stipules are either small or absent. Flowers are red, pink, purple or white in colours. Pods generally contain two seeds. Seeds are shaped like a lens. In fact, lens is the *Latin* word for lentil.

In lentil flowering starts after 6-7 weeks of planting. Early varieties mature in 80-110 days, while late varieties mature in 125-135 days (*Lens culinaris* Medik. <http://www.hort.purdue.edu/newcrop/CropFactSheets/lentil.html>).

**Nutrient Requirement**

Nitrogen requirement in lentil is fulfilled by N<sub>2</sub> fixation and on an average their residues contribute around 20 kg N ha<sup>-1</sup> to the soil N pool (McNeil and Materne, 2007). Inoculation of lentil seeds with *Rhizobium* is reported to result in a significantly higher nodule dry weight (Namdeo *et al.*, 1996).

During early seedling phase growth is dependent upon inorganic (soil or fertilizer) nitrogen, but once nodules are established, symbiotically fixed nitrogen accounts for around 85% of the nitrogen assimilated through the entire duration of the crop (van Kessel, 1994). Nitrogen requirement is



large during reproductive growth phase. During later period of pod growth nitrogen fixation rate decreases due to competition for photosynthates with developing seeds, combined with a declining photosynthetic capacity of the ageing canopy and the onset of adverse environmental conditions (Whitehead *et al.*, 2000). Nearly 70% of seed stored nitrogen is derived from vegetative parts by remobilization (Kurdali *et al.*, 1997). Phosphorus and zinc requirements of lentil are similar to the other legume crops. Phosphorus deficiency leads to increase in length of primary root, length and number of lateral roots, root hairs and root meristem volume in lentil seedlings (Sarker and Karmoker, 2009). However, it is highly sensitive to iron deficiency (Queensland Government. Primary Industries and Fisheries <http://www2.dpi.gov.au/fieldcrops/9274.html>). Application of zinc along with phosphorous increases plant growth and yield significantly rather than the application of phosphorus alone. Addition of *Rhizobium* and VAM fungi also improves growth, yield and harvest index of the crop (Krishnareddy and Ahlawat, 2008; Panwar and Thakur, 1995).

### Crop Phenology

It is a quantitative long day or day neutral plant (Andrews and McKenzie, 2007). The duration from emergence to appearance of first flower has been distinguished into four phases viz., pre-emergence, pre-inductive, inductive and post-inductive. The first two phases and last phase are insensitive to photoperiod, but sensitive to temperature. The reciprocal of the duration of inductive phase is a linear function of both photoperiod and temperature. The critical photoperiod decreases with increase in temperature and the duration of inductive phase can be calculated from a summation of the amounts by which successive day lengths exceed the critical photoperiod, a value (the photoperiodic sum) characteristic of the genotype is reached (Summerfield *et al.*, 1985; Roberts *et al.*, 1986).

In lentil all developmental phases except emergence to flowering depends upon thermal time. Sowing to emergence, flowering to physiological maturity, and physiological maturity to harvest require 115°Cd, 546°Cd and 270°Cd above the critical temperature, respectively. Emergence to flowering is dependent upon accumulated photothermal time and requires 278 days (photothermal) above the critical temperature. The base temperature for growth and development up to flowering is reported to be 2 °C and 6°C after flowering (Andrews and McKenzie, 2007). LENMOD, a lentil crop growth model, has been developed to provide greater understanding of how different climatic factors, viz. air and soil temperature, solar radiation, moisture availability and wind speed etc., interact to determine growth and yield in this crop. The model also predicts the region where lentil may be grown successfully (Andrews and McKenzie, 2007).



### Seed Development

It is a self-pollinated crop. Sucrose is the main soluble sugar in developing seeds and fruit walls, while glucose and fructose are present in very low level. Sucrose synthase is the predominant sucrolytic enzyme in the developing seeds. Acid invertase is associated with fruit walls elongation and had little activity in seeds. Substantial increase in sucrolytic enzymes is observed at the time of maximum seed filling stage. High sink strength (rapid seed filling) correlates with high activity of sucrose synthase. Fruiting structures recapture and reutilize respired carbon dioxide by phospho enol pyruvate carboxylase (PEP carboxylase) activity. High activity of isocitrate dehydrogenase and malic enzymes in developing seeds has been reported to be linked with deposition of proteins in seeds (Chopra *et al.*, 2003). Biomass accumulation by fruit walls and seed is higher in large seeded types than in small seeded types. Larger seeded genotypes also have high activity of enzymes acid invertase and alkaline invertase for an extended period, and these have been attributed to larger cell division phase resulting in larger seed size and biomass. Large seeded types are also reported to have increased level of sucrose synthase activity during maturation phase, supposed to be responsible for enhanced seed sink strength. Higher fruit walls biomass is considered responsible for providing more reserves for contained developing seeds, and hence determining the seed size (Chopra *et al.*, 2005a).

### Abiotic Stresses

Major abiotic stresses limiting lentil productivity world wide are drought coupled with heat stress. In comparison to other temperate grain legumes lentil is relatively more tolerant to drought. Crop is also susceptible to waterlogging and soil pH (<6.5), and highly sensitive to soil salinity (Katerji *et al.*, 2001). Flowering stage is the most critical phase to water stress in lentil (McKenzie and Hill, 2004).

Under well watered condition stomatal conductance in lentil is reported to vary from 169 to 400 m mol m<sup>-2</sup> sec<sup>-1</sup>. Water stress causes significant reduction in it. As leaf water potential decreases below -2.5 MPa, stomatal conductance may range 19 to 100 m mol m<sup>-2</sup> sec<sup>-1</sup> (Leport *et al.*, 1998; Shrestha, 2005). However, no genotypic differences in stomatal response to water deficit are reported (Shrestha *et al.*, 2006a) and; therefore, the stomatal conductance is not suggested as a selection criterion in this crop.

Under normal condition at flowering stage net photosynthetic rate in lentil is reported to vary from 16.6 to 17.0  $\mu$ mol m<sup>-2</sup> sec<sup>-1</sup> (Leport *et al.*, 1998; Shrestha, 2005), and decreases to 8.0  $\mu$ mol m<sup>-2</sup> sec<sup>-1</sup> during podding (Shrestha, 2005). Water stress causes significant reduction in net photosynthetic rate, but genotypic differences with respect to their sensitivity to water deficit are not observed (Shrestha, 2005); therefore, the photosynthetic rate is also not suggested as a selection criterion in this crop.



The strategy to combat drought has been to match the development of crop with the period of soil moisture availability. Genotypes with early seedling establishment, early and rapid biomass production, early flowering and maturity have been selected for regions of low rainfall. Under controlled condition in glass house, it is observed that water-deficit reduced seed yield by 70%, but the genotypes did not show variation in vegetative growth or seed yield under well-watered or water-deficit conditions. Differences were significant with respect to number of flowers, fruiting node, pods, seeds and harvest index. The small seeded genotypes produced the highest number of fruiting nodes, greater number of flowers, pod and seeds than the large seeded genotypes. Water-deficit reduced plant height by about 20%, leaf area by 48-81% and total dry matter by 60% compared with well-watered plants. Water-deficit reduced flower number by 35-46%, and increased seed abortion by 17-46%. Water-deficit had no effect on the maximum seed growth rate, seed-fill duration or the final seed size. Reduced seed yield under water-deficit condition was attributed mainly due to reduction in pod and seed numbers (59-70%) rather than individual seed growth rate and seed size (Shrestha, *et al.*, 2006b). Small seeded genotypes perform relatively better than the large seeded types under drier environment (Erskine, 1996).

When compared to other temperate grain legumes, lentil is considered as tolerant to low temperature, but extremely low temperature causes yield losses. Genotypic differences in low temperature tolerance occur in lentils as photothermally sensitive genotypes are more tolerant to low temperature than the photothermally insensitive genotypes (Keatinge *et al.*, 1996). Also, large seeded genotypes are more tolerant to cold than the small seeded genotypes (Erskine, 1996). Cold tolerant lines, for sites where winter temperatures are as low as -12 to -30°C, have also been identified by field screening of cultivars growing in extreme cold prone regions (Andrews and McKenzine, 2007). Wild lentils are considered as the potential source for the improvement of cultivated lentil (Ferguson and Robertson, 1999).

Early growth of the crop is slow and so it poorly competes with weeds and, therefore, to prevent yield losses it is necessary to keep field free of weeds (Curran *et al.*, 1987).

### Yield Attributes

Water-use efficiency of lentil is much higher than any legume such as broadbean and soybean (about 2 kg m<sup>-3</sup>), (Katerji *et al.*, 2001). High yield potential is associated with rapid early stage growth, early flowering and maturity, long reproductive period, greater number of seeds per pod, high total dry matter, high harvest index (Shrestha *et al.*, 2005). Yield determining factors are reported to be different under irrigated and unirrigated conditions. Under unirrigated condition seed yield is primarily determined by total dry matter production, mean temperature and total



degree days from podding to maturity, while under irrigated condition it is determined by dry matter in roots at vegetative stage, total dry matter, rate of dry matter production and total degree days from flowering to podding (Bhattacharya, 2009). Harvest index of the crop is poor. Grain yield and dry matter production are positively correlated with pod number, plant height, and number of primary and secondary branches, but negatively correlated with test weight. Tall genotypes with higher pod number and low branching are suggested for improvement in lentil yield and harvest index (Singh, 1977). Mean crop growth rate (CGR) is also reported to be positively correlated with seed yield, and it is the maximum during pod development stage (Tripathi and Singh, 1989).

### Constraints

Major constraints with the crop are poor biomass production, seed yield and harvest index. In wild progenitors, biomass production is around 0.72 tonnes/ha, harvest index around 19%, and seed yield 0.11 tonnes/ha. Productive land races have higher biomass (3.52 tonnes/ha), improved HI (34%) and seed yield (1.13 tonnes/ha). Seed yield has further been improved by selection and hybridization (1.32-1.95 tonnes/ha). Consistent seed yield improvements have not been associated with consistent increase in harvest index. There is a positive correlation between seed yield and biomass. Nitrogen harvest index increases more rapidly than harvest index, and is likely to improve further in future. Therefore, it is expected that further seed yield improvement will depend on increase in nitrogen accumulation. Reliance on nitrogen fixation must be supported by increased photosynthetic capacity, and therefore by vegetative biomass (Whitehead *et al.*, 2000). Summerfield and Lawn (1987) opined that poor residue productivity of lentil could be further depressed, similar to that as observed in cereals, if improved seed yield are sought through genetic selection for increased harvest index. There are no signs of yield plateau for lentil, and, therefore, there is prospect for improvement in biomass and seed yield (Whitehead *et al.*, 2000).

### LATHYRUS

*Lathyrus* belongs to family Fabaceae, sub-family Faboideae and tribe Viciae, which represents approximately 187 species and subspecies. Species which are grown for food include *L. sativus*, *L. cicera*, and less commonly *L. ochrus* and *L. clymenum*. *L. sativus* is primarily grown for seeds, while *L. cicera*, *L. clymenum* and *L. ochrus* are used both for production of seed and green fodder. One species, *L. tuberosus*, develops tuber, rich in starch and is cultivated as root vegetable. Less known species, viz. *L. tingitanus*, *L. latifolius* and *L. sylvestris* are solely used for green fodder production (Rybanski *et al.*, 2008; *Lathyrus* *Lathyrus*. <http://en.wikipedia.org/wiki/lathyrusLathyrus>).

The *L. sativus* is an annual legume crop and grown in Eurasia, North America, temperate parts of South America and East Africa (Smartt, 1990). It is commonly known as khesari or batura (India), Shan li



dou (China), grass pea, chickling pea or India vetch (UK and North America), almorta, muela tito or guijo (Spain), pisello bretonne or cicerchia (Italy) alverjas (Venezuela), gilban (Sudan), guaya (Ethiopia), matri (Pakistan), gesette (France), and cicerchia, pisello bretonne (Italy).

Vavilov (1951) described two separate centre of origin for *Lathyrus*. One, the central Asiatic Centre, which includes northwest India, Afghanistan, the Republic of Tajikistan and Uzbekistan, and western Tian-Shan, and the second, the Abyssinian centre. Small seeded forms are found in southern and southwest Asia, where as highly cultivated forms with large white seeds and flowers, in the Mediterranean region (Jackson and Yunus, 1984). On the basis of principal components analysis, it is suggested that *L. sativus* could be divided into two geographical origins: Indian sub-continent and Mediterranean/European. Generally Mediterranean/European lines are higher yielders with large seed size and later phenology (Hanbury *et al.*, 1999). The *Lathyrus* is an ancient crop of India and its existence is from 2000-1500 BC (Saraswat, 1980). Archeological and phytogeographical evidences indicate that the origin of *L. sativus* cultivation is in the Balkan Peninsula, in the early Neolithic period, dated to the beginning of the 6<sup>th</sup> millennium BC (Kislev, 1989; Anonymous, 2000). The *L. sativus* ecotypes are classified on the basis of flower colour, marking on pods, and size and colour of seeds (Anonymous, 2000).

The *L. sativus* is widely cultivated as a food crop, and is an important crop of economic significance in India, Bangladesh, Pakistan, Nepal, China, Myanmar and Ethiopia (Campbell *et al.*, 1994; Yadav and Mehta, 1995). In India, it is widely grown in Madhya Pradesh, Chattisgarh, West Bengal, Maharastra and parts of eastern Uttar Pradesh, and covers 1.6-2.0 m ha land and contributing about 8-10% of the food legumes in the country (Dahiya, 1976).

*L. sativus* seeds are boiled and consumed as a pulse, used for dal preparation and bread making. In India, Ethiopia and other developing countries it is used as a part of the diet of the poor in the time of famine. Mixed with oil cake and salt, seeds are used as feed for poultry and livestock. Seeds are also used in homeopathic medicine (Anonymous, 2000).

## NUTRITIONAL COMPOSITION OF SEED

*Lathyrus* seeds are rich in protein and on dry weight basis contains about 26.3% protein, 3.2% ash, 0.7% fat and 5.5% crude fiber (Dhiman *et al.*, 1983). It contains 18% higher protein than gram, 25.0% higher than field peas, 26.9% higher than faba bean (Yan *et al.*, 2006). Seeds are rich in lysine but deficient in methionine, cysteine and tryptophan (Ravindran and Blair, 1992). Seeds contain antinutritional substances,

which hinder free nutritional utilization in monogastric animals (Hanbury *et al.*, 2000) and human beings. Chemical composition of lathyrus seeds is given in Table 6.

**Table 6.** Chemical composition of *Lathyrus* seeds.

Component	Range
Water (%)	7.50-8.20
Starch (%)	48.00-52.30
Protein (%)	25.60-28.40
Acid detergent fibre (%)	4.30-7.30
Ash (%)	2.90-4.60
Fat (%)	0.58-0.80
Calcium (mg kg <sup>-1</sup> )	0.07-0.12
Phosphorus (mg kg <sup>-1</sup> )	0.37-0.49
Lysine (mg kg <sup>-1</sup> )	18.40-20.40
Threonine (mg kg <sup>-1</sup> )	10.20-11.50
Methionine (mg kg <sup>-1</sup> )	2.50-2.80
Cysteine (mg kg <sup>-1</sup> )	3.80-4.30

Source: Campbell *et al.*, 1994

Prolonged consumption of *L. sativus* causes lathyrism in human beings and animals (Ganapathy and Dwivedi, 1961). Lathyrism occurs in the form of neurolathyrism, osteolathyrism and angiolathyrism (Grela *et al.*, 2000). Osteolathyrism is characterized by metabolic disturbances in the synthesis of elastic compounds of mesenchymal tissues and the skeletal system, causing skeletal deformities that are connected with disorders in the growth of cartilages and bones. Earlier selenium was thought the cause of lathyrism as *L. sativus* seeds are richer in selenium than other pulses (Rudra, 1952), but now it is established that the disease is due to an acidic neurotoxic amino acid,  $\beta$ -N-oxalyl-L- $\alpha$ ,  $\beta$ -diaminopropionic acid, described in short as  $\beta$ -ODAP, also known as  $\beta$ -oxalyl-amino-alanine (BOAA), present as a free amino acid in *L. sativus* seeds (Rao *et al.*, 1964; Murti *et al.*, 1964). Other neurotoxic amino acids, identified in *Lathyrus sativus* include homoarginine in seeds, homoserine and izoxazoline like substances and homoserine like substances in sprouts and all parts of plant except the ripe seeds (Grela *et al.*, 2001). In some species of *Lathyrus* and some other legumes,  $\alpha$ -amino-adipinic acid has been



detected, which is reported to be highly toxic in comparison with  $\beta$ -ODAP (Grela *et al.*, 2000). The  $\beta$ -ODAP is slowly converted into its isomer  $\alpha$ -ODAP. The inter conversion is facilitated upon heating. The  $\alpha$ -isomer is approximately 5% of the total ODAP content in seeds (Roy and Rao, 1968; Yan *et al.*, 2006). In animals, the  $\alpha$ -isomer is less neurotoxic than the  $\beta$ -isomer (Chase *et al.*, 1985). The  $\beta$ -ODAP is water soluble, therefore, easily leached out of the seeds. Steeping seeds in large volume of water for 3 minutes leaches out approximately 30% of  $\beta$ -ODAP, with greater loss when hot water is used (Tekele-Haimanot *et al.*, 1993). Boiling seeds and discarding the water reduces  $\beta$ -ODAP level up to 90% (Padmajaprasad *et al.*, 1997). Seeds also contain considerable amount of tannin and phenolic substances as well as trypsin and chemotrypsin in inhibitory activity (Cambell, 1977).

### Plant Morphology

*L. sativus* is an herbaceous winter annual. Plants are 30-90 cm tall, much branched sub erect, straggling or climbing type with well developed tap root system, which are having rootlets covered with small cylindrical, branched nodules, generally clustered together in dense groups. Roots are very hardy and penetrating; hence plant can grow on a wide range of soil types including very poor soil and heavy clays. Stem is quadrangular, winged with margins. Stipules are prominent. Leaves are opposite and pinnate having one or two pairs of leaflets with a simple or branched tendril. Flowers are pedicelate, axillary, solitary, and bright blue, reddish purple, red, pink or white in colour and are about 1.5 cm long. Pods are oblong, flat, slightly budging over the seed, about 2.5-4.5 cm in length, 0.6-1.0 cm in width and slightly curved. Pods contain 3-5 seeds, which are 4-7 mm in diameter, white, and brownish-grey or yellow in colour (Campbell, 1997).

During germination hard seededness completely prevents imbibitions (Chinnasamy and Bal, 2003). Seeds may germinate at temperature as low as 2-3° C. Plants are able to withstand frost as cold as -8° C. Germination is hypogeal. The first leaf is small; scale-like, often fused with two lateral stipules. The second leaf is subulate, connected at the base with stipule (Campbell, 1997). Large morphological variation, especially in vegetative characters occurs in different genotypes. The average sum of necessary heat for the vegetation period of 80–100 days is estimated to be 2000–2400°C (Interactive Agricultural Ecological Atlas of Russia and Neighboring Countries [http://www.agroatlas.spb.ru/en/content/cultural/Lathyrus\\_sativus\\_K/](http://www.agroatlas.spb.ru/en/content/cultural/Lathyrus_sativus_K/)).

### Nitrogen Fixation

It is a leguminous crop and fixes atmospheric nitrogen. Therefore, it is a suitable crop for long term sustainable farming system. During pre



flowering stage more nodules are formed on primary roots than on lateral roots. Nodules on lateral roots start developing during flowering stage. Nodule number declines during fully developed pod stage (80 days after sowing). In general nodulation gradually increases from pre-flowering, reaches its peak during flowering, and decline during fully developed pod stage. Nitrogenase activity also follows a similar trend (Das *et al.*, 2001).

### Reproductive Growth

It is a self pollinated crop and out crossing ranges from 9.8-27.8% (Campbell, 1997). In India large variation occurs with respect to days to 50% flowering (47-94 days) and days to maturity (86-127 days). Small seeded genotypes flower and mature earlier than the genotypes with bolder seeds (Campbell, 1997).

The accumulation of fresh and dry weight in fruit walls and seeds during development indicate that fruit walls follow a sigmoid curve, while seeds follow a linear trend. During maturation, moisture content of fruit walls and seeds decreases due to dehydration (Chinnasamy and Bal, 2003). On dry weight basis of seed, content of starch, protein, lipid and thiamine increases, while soluble sugars, sugars, total amino acids, essential and sulphur amino acids, ash and its alkalinity, magnesium, phosphorus, vitamin C, riboflavin, carotenoids,  $\beta$ -carotene, and chlorophyll also increased. Content of dietary fibre, iron, calcium and phytic phosphorus follow variable trend. Protein accumulation in seeds increases progressively with maturity and has a positive correlation with seed weight accumulation (Chinnasamy and Bal, 2003; Lisiewsk *et al.*, 2003).

Variation in the amount and rate of synthesis and accumulation of  $\beta$ -ODAP with the ontogeny has been observed, and it is reported that the rate of synthesis and accumulation of  $\beta$ -ODAP is developmentally controlled in plants. The maximum accumulation occurs during two separate developmental stages. During reproductive stage, enhanced rate of synthesis and accumulation occurs in fruit walls, embryo and to a lesser extent in roots. Early in the vegetative phase an accelerated rate of accumulation occurs in shoot and root meristems. As  $\beta$ -ODAP is toxic to herbivore, therefore, it is suggested that it serves as a defense mechanism against herbivores. The plants are more vulnerable to herbivore during the early vegetative stage and when pods are maturing. During middle vegetative phase very little ODAP accumulation occurs in leaf and stem tissues. It is given that during evaluation of these species as developmentally regulated genetic mechanism, which selectively enhanced the biosynthesis of this neurotoxin during the most vulnerable stage of plant development, has been evolved. The  $\beta$ -ODAP level in various plant parts has also been estimated by Mehta *et al.*, (1991). The role of  $\beta$ -ODAP in physiological mechanism, if any, is not known as yet. (Addis and Narayan, 1994), but Lambein *et al.*, (1994) hypothesized that it functions as a carrier molecule for zinc iron, and soils depleted in Zn or poor in



available Zn and with high iron content are probably responsible for high content of  $\beta$ -ODAP in seeds.

The  $\beta$ -ODAP content in seeds varies with genotypes, the region of cultivation, time of crop harvest and the size of seeds, etc. *Lathyrus* cultivars of temperate region contain lower level of lathyrogens than those from tropical and subtropical regions (Dahiya and Jeswani, 1975; Grela *et al.*, 2000; 2001). Land races grown by farmers in India have low yield potential and high neurotoxin content (0.2 to > 0.7%), and shows instability over location and season (Kumari and Prasad, 2005). Concentration of neurotoxins in seeds collected from various locations in Madhya Pradesh, India indicated variations in  $\beta$ -ODAP content from 0.1 to 2.5%. Seeds from rice-wheat zone contained higher concentration of  $\beta$ -ODAP than those collected from rice zone. Seeds from rice zones were smaller in size and lighter in colour, and considered harmless upon consumption (Nagarajan and Gopalan, 1968). In Mediterranean type environment, genotype is the most important determinant of  $\beta$ -ODAP concentration in seeds while environment has less influence, and genotype  $\times$  environment interaction has no effect on seed  $\beta$ -ODAP content (Hanbury *et al.*, 1999).

In India, at present there is ban on the cultivation and sale of *Lathyrus* in almost all the states under Prevention of Food Adulteration Act, but three states viz., Bihar, Madhya Pradesh and West Bengal still permit its cultivation, most likely for fodder use. But the fact is far from ground reality, and it has been found that except in the southern states of the country *Lathyrus* is adulterated mainly with the chickpea flour, one of the most popular ingredients of the Indian house hold (Dixit *et al.*, 2008).

### Abiotic Stress Resistance

*L. sativus* tolerates waterlogging during seedling stage. It has immense potential to tolerate drought and consistence production in low input environment (Lal *et al.*, 1986; Kaul *et al.*, 1986; Rathod, 1989; Campbell *et al.*, 1994). Net photosynthetic rate, transpiration rate and water-use efficiency in *Lathyrus* genotypes are reported to be  $10\text{--}14 \mu\text{mol m}^{-2} \text{sec}^{-1}$ ,  $3\text{--}7 \text{ mmol H}_2\text{O m}^{-2} \text{sec}^{-1}$ , and  $2\text{--}3 \text{ mmol mol}^{-1}$ , respectively (Yang *et al.*, 2004). Under drought there is considerable reduction in net photosynthetic rate and transpiration rate, but significant improvement in water-use efficiency. Linear correlation has been reported between stomatal density, stomatal aperture, photosynthetic character and seed  $\beta$ -ODAP content at different water levels (Yang *et al.*, 2004). Water-use efficiency is reported to be positively correlated with stomatal density, but negatively correlated with stomatal aperture. Net photosynthetic rate, transpiration rate, and seed  $\beta$ -ODAP, starch and protein contents are reported to be positively correlated to stomatal aperture and negatively correlated with stomatal density (Yang *et al.*, 2004). These correlations are enhanced under drought. It is given that  $\beta$ -ODAP might serve as an amino acid to anticipate in the osmotic adjustment of plant cells (Yang *et*



*al.*, 2004).  $\beta$ -ODAP is also correlated with ABA signaling, polyamine metabolism, reactive oxygen species (ROS) scavenging (Xing *et al.*, 2001; Zhou *et al.*, 2001).

Zhang and Mu (2009) observed the effect of salinity and alkalinity stresses on germination, growth, and photosynthesis on *Lathyrus quinquenervius* and observed that at low stress intensity, the effects of saline stress and alkaline stress were similar. Compared with salinity stress, high alkaline stress intensity inhibited germination, growth, photosynthesis and root system activity, and led to a sharp increase in  $\text{Na}^+$  and anion imbalance in the shoots, as well as enhanced  $\text{H}_2\text{O}_2$  and malondialdehyde content, resulting in severe intracellular oxidative stress. They also indicated that the accumulation of organic acid was a central adaptive mechanism by which *L. quinquenervius* maintained intracellular ionic balance under alkaline stress. They suggested that *Lathyrus quinquenervius* may enhance organic acid synthesis to remedy the shortage of negative charge resulting from the massive influx of  $\text{Na}^+$  and decreased inorganic anions. In addition, saline stress and low alkaline stress slightly enhanced the activities of superoxide dismutase (SOD) and ascorbate peroxidase (APX), but did not affect catalase (CAT) activity. However, strong alkaline stress is reported to significantly enhance the activities of SOD and APX, and reduce CAT activity. Zhang and Mu (2009) proposed that enhanced activities of SOD and APX might be a vital mechanism by which *L. quinquenervius* resists oxidative stress caused by alkaline stress.

*L. sativus* is a wild relative of protein pea and, therefore, is an useful genetic resource for the acquisition of interesting stress resistance trait (Ochatt *et al.*, 2002).

### Yield Attributes

Plant height, days to podding and seeds per pod are the principal yield components in *Lathyrus*. Seed yield is positively and significantly associated with plant height, days to flowering, days to podding, pods per plant and seeds per plant. Test weight, is negatively, but nonsignificantly correlated with seed yield. Plant height has a significant positive correlation with days to flower. The  $\beta$ -ODAP content in seeds is reported to be significantly and negatively correlated with the number of branches, days to flowering, days to podding, pods per plant, seeds per pod and seed yield (Kumari and Prasad, 2005).

While breeding for low neurotoxin, it is suggested that emphasis should be laid on early maturing types with small seeds. It is the testa pigment which is reported to have some association with the neurotoxin content in the seeds, as the seeds with dark grayish colour mottling contain higher amounts of neurotoxin. Small seeds with light cream colour have been suggested as selection index for low neurotoxin level (Dahiya, 1976). However, conflicting reports are also available and, therefore, there is a need to examine large number of genotypes and to identify suitable



morphological marker for rapid screening of genotypes low in  $\beta$ -ODAP content.

### Constraints

Though it is used as a pulse crop for at least 8000 years but no sincere effort has been made to improve this crop. The crop is poor yielder, as in India the average yield realized is around 728 kg ha<sup>-1</sup> (Ministry of Agriculture, 1993). It is also having low harvest index. Small seeded lines have shattering problem. Presence of neurotoxin and trypsin inhibitor make this crop unfit for human consumption. Development of a most compact growth habit, along with increased seed yield and elimination of neurotoxin is urgently required as the crop has immense potential in semiarid areas of developing countries. Genetic detoxification of  $\beta$ -ODAP is suggested to be the most feasible method for developing a safe crop rather than by other physical methods of treatment.

Regenerating plants from explants derived from stem, leaf and roots have been successful and the resulting plants were having high amount of somaclonal variation in plant habit, and it is suggested that this technique may be exploited as an alternative means in production of agronomically desirable types for low  $\beta$ -ODAP lines, rather than by following conventional breeding by crossing and back crossing (Anonymous, 2000). However, in India efforts are going on to develop genotypes through use of both hybridization and somaclonal for low  $\beta$ -ODAP content. Some success has been achieved in developing lines with low  $\beta$ -ODAP in India and ICARDA, Syria (Department of Agriculture and Food. Govt. Western Australia. Crops <http://www.agric.wa.gov.au>).

### RAJMASH

Rajmash, botanically called as *Phaseolus vulgaris* L., is a member of family Fabaceae, sub-family Faboideae, and tribe Phaseoleae. It is also called as *rajmash*, *rajma*, French bean, kidney bean or common bean or snap bean, navy bean, chili bean, and red bean. Its place of origin is supposed to be the heights of Middle America and Andes. However, Vavilov (1951) opined that primary centre of origin is Mexico and Central America, and Peruvian-Ecuadorian-Bolivian part of South America is the secondary centre of origin of French bean. Genus *Phaseolus* is having around 50 species and *Phaseolus vulgaris* L. represents around 90% of the cultivated species world wide.

French bean cultivating countries are Brazil, Columbia, USA, Canada, Ethiopia, China and Turkey, and Brazil is the major producer. Globally it is cultivated in 28 m ha land area and the total production is around 19

m tonnes. In India, French bean is cultivated in an area of 0.1 m ha and the major French bean growing states are Jammu & Kashmir (10,000 ha), and Maharashtra (6,000 ha). It is also cultivated in the hilly tracks of Uttar Pradesh and Himachal Pradesh, Nilgiri (Tamilnadu) and Palni (Kerala) hills, Chickmagalur (Karnataka), and Darjeeling hills (West Bengal). In India, under optimal conditions yields are about 2.0-2.5 t ha<sup>-1</sup> (Ahlawat <http://nsdl.niscair.res.in/bitstream/123456789/508/1/FRENCH+BEANS-+formatted.pdf>).

Its young pods as well as mature seeds are used for consumption. Seeds and immature pods are good source of protein, calcium and iron. Dry seeds contain nearly 24% protein. Immature pods are also used as salad, in meat and fish dishes, and canned. In East Africa tender leaves are also consumed. French bean is also used as a fodder crop.

### Cultivation

French bean is cultivated in tropical and temperate regions where temperature is around 21°C. Crop grows better in temperature range of 16-24°C with annual rainfall of 50-150 cm. Temperature below 10°C is detrimental for crop growth, while temperature exceeding 35°C causes abscission of buds and flowers. Crop is also highly susceptible to frost, waterlogging, and salinity. Though it may be cultivated on different types of soils ranging from sandy to heavy clay, but well drained loams are the best for the cultivation of crop. Ideal pH for crop cultivation is between 5.2-5.8, (Ahlawat <http://nsdl.niscair.res.in/bitstream/123456789/508/1/FRENCH+BEANS-+formatted.pdf>). In India it is cultivated in *rabi* as well as in *kharif* seasons both depending upon the location and the climatic conditions of the region. In India French bean cultivation was initiated in hilly areas of northwestern part of the country, but because of high productivity, nutritive status, high profit and constant market demand, farmers in Lower Gangetic Plain of India have also started to grow this crop in *rabi* (Tripathi *et al.*, 1986).

### Morphology

French bean plants are annual and herbaceous. In India both bushy as well as trailing type varieties are grown. Leaves are trifoliate. Plants have terminal raceme with axillary bisexual flowers. Flowers are white, pink or yellow in colour, depending upon the variety, and are self fertilized (Begum *et al.*, 2003).

### Fertilizer Requirement

The fertilizer requirements of the crop vary with variety and the environmental conditions (Negi and Shekhar, 1993; Saini and Negi, 1998). Although French bean is a leguminous crop, but it either nodulates poorly or does not nodulate at all. Therefore, as compared to other



leguminous crops, its nitrogen requirement is considerably high. Generally 100-120 kg N and 60 kg  $P_2O_5$  ha<sup>-1</sup> is ideal for optimal crop yield. Applied K and micronutrients have no significant effect on yield improvement of the crop. But when crop is repeatedly grown in the same field with out applying K under intensive cropping system, yield is reduced, therefore, it is recommended to apply about 38 kg ha<sup>-1</sup>  $K_2O$  (Rana *et al.*, 2003). However, in Sri Lanka Sangakkara (1996) observed that both rate and ratio of potassium application influences vegetative growth, pod and seed yield, and quality of seeds in terms of germinability. He also reported that for production of immature pods potassium should be applied during sowing, and for higher seed yield it should be applied during planting and at flowering stages. Fertilizer placement at 10-25 cm depth in soil is reported to promote growth and development of root and shoot of the crop (Chaib *et al.*, 1984).

### Abiotic Stress Resistance

French bean is a  $C_3$  crop. Net photosynthetic rate, transpiration rate, stomatal conductance and water-use efficiency are reported to be 15.72  $\mu\text{mol m}^{-2} \text{sec}^{-1}$ , 5.08  $\text{mmol m}^{-2} \text{sec}^{-1}$  and 3.09  $\mu\text{mol CO}_2 \text{mol}^{-1} \text{H}_2\text{O}$ , respectively. Under water deficit condition photosynthetic rate and transpiration decreases significantly, while water-use efficiency increases (Souza *et al.*, 2005).

As compared to other pulse crops of the country, French bean has shallow root system; therefore, it is highly susceptible to moisture stress of any stage of crop development. Generally *kharif* sown crop does not need any irrigation if rainfall distribution is even. However, *rabi* sown crop requires irrigation and 25 days after sowing stage (DAS) is the critical stage for irrigation. For optimal yield of *rabi* sown crop in NEPZ of the country three irrigation at 25, 75 and 100 DAS, and in Central Zone four irrigations at 25, 50, 75 and 100 DAS are recommended for optimal yield. Although crop is shallow rooted and susceptible to moisture stress, but its water requirement is low, and in India it can be grown even under dry land condition, where one supplementary irrigation has been found to enhance crop yield from 2.72 to 3.94 t ha<sup>-1</sup> (Sarkar *et al.*, 2000).

Although deep rooting offers access to more water resulting in higher stomatal conductance and canopy temperature depression, but does not result in greater yield. Higher yield under drought is linked with partitioning of photosynthates. While working at CIAT (International Center for Tropical Agriculture, Cali, Colombia), Beebe *et al.* (2009) suggested that pod partitioning index (pod biomass at harvest as a per cent of total biomass at mid pod filling) and pod harvest index (grain as per cent of total pod biomass) are the ideal traits to identify drought stress tolerant genotypes. They also reported that improved partitioning that is selected under drought stress also contributes to yield under favourable condition. Inefficiencies in partitioning in common bean are an ancestral

trait associated with survival mechanism of the wild beans in its native habitat (Beebe *et al.* 2009).

Crop is highly sensitive to salinity, and threshold level of soil ECe is reported to be 1 dS m<sup>-1</sup>. (Ahlawat , <http://nsdl.niscair.res.in/bitstream/123456789/508/1/FRENCH+BEANS-+formatted.pdf>). Under the influence of NaCl and Na<sub>2</sub>SO<sub>4</sub> induced salinity conditions, an increase in the thickness and moisture content of leaves is reported (Bhivare and Nimbalkar, 1984). It is also observed that under the influence of NaCl or Na<sub>2</sub>SO<sub>4</sub> induced salinity conditions, contents of Na, Ca, Fe and Mg increases, and levels of N, K, Cu and Zn decreases (Bhivare and Nimbalkar, 1984).

### Constraints

Though the crop has been successfully introduced in northern plain of the country, the major limitation for its production not been popularly accepted by the farmers is the lack of market. Strengthening of marketing facility will certainly boost the crop productivity.

## FIELD PEA

Field pea belongs to family Fabaceae, sub family Faboideae, tribe Viciae and genus *Pisum*. Field pea (*P. sativum* L.) is an annual cool season crop. It is a native of Southwest Asia, and is among the first few crops cultivated by man. Pea has wide genetic diversity and bold seeded forms are supposed to be having centre of origin in Mediterranean region. From Palestine or Egypt it reached to Europe (Cole, 1961). In 4800-4400 BC presence of pea was traced out in Niel delta area of Egypt. In the southern India and in its Gangetic basin, peas were there in second half of 2<sup>nd</sup> millennium BC (Zohary and Hopf, 2000). The term pea has been taken from Latin word *Pisum*. The major part of field peas is used or sold as dry pea.

Dried peas are being used as food for more than 10,000 years. Dried peas were found in a Bronze Age village unearthed in Switzerland, which was dried in about 7,800 B.C. It is reported that when the German archaeologist Heinrich Schliemann discovered ancient Troy of Homer's *Iliad* fame, he also found dried beans, which were edible. Earlier, peas were eaten dried or ground. In the sixteenth century Italian and Dutch gardeners developed tender varieties of peas for cooking and eating fresh. (Field Peas, [http://www.harvestwizard.com/2007/04/field\\_peas\\_field\\_peas\\_are.html](http://www.harvestwizard.com/2007/04/field_peas_field_peas_are.html)).

Field peas are an important cash crop in Ethiopia, China, India, Canada and Russia and in some parts of the United States. Major field pea producing countries are Russia, China, India, Canada, Europe, Australia and the United States. It is cultivated in an area of 25 m acre world wide.



## Morphology

It is an annual plant with trailing habit. Leaves are alternate, compound, and apical and some times sub apical leaflets are modified into tendrils. Some recently developed varieties are devoid of leaflets, which are complete modified into tendrils. Each node has a pair of leafy stipule, which is present at the base of each leaf. Flowers are born on racemes, which arise from the axils of the leaves.

On the basis of growth habit there are two main types of pea. One type has normal leaves and vine lengths of three to six feet; the second type is the semi-leafless type that has modified leaflets which are reduced to tendrils, resulting in shorter vine lengths of two to four feet. Pea normally has a single stem but can branch from nodes below the first flower. Field peas are a cool-season vegetable just like garden peas and sugar peas, but they are allowed to dry on the vine before harvest. However, on the basis of colour of the cotyledons; green pea and the yellow pea are the two most common types of field peas.

Peas are having indeterminate growth. Early varieties are non responsive to photoperiod and vernalization, while in late varieties flowering is advanced by such treatments (Pate, 1975).

Field pea pods grow to approximately 7.5 cm long and contain between four and nine seeds. Immature pods are also harvested and raw seeds are used as vegetable. The taste of seeds is best when the pods are fully grown but the seeds have not attained full size. Fresh seeds are also frozen or canned. Dried peas have been cultivated and used for food for more than 10,000 years. Dried peas are used in soups, pastas, cereals, and purées. Besides these raw as well as dried seeds are used for making a number of food preparations and dished in different parts of the world. Split seeds are used as *dal*.

## Nutritional Composition

The nutritive value of edible portion of raw, split, and mature peas seeds, and raw green peas are given in Tables 7 and 8, respectively. Raw, split, and mature pea seeds contain nearly 25% protein, and are rich in K, Mg, P, Ca, several vitamins.viz, Vitamin C. Field pea has high levels of amino acids, lysine and tryptophan, which are relatively low in cereal grains. Field pea contains approximately 21.25% protein. They have high levels of carbohydrates and contain 86.87% total digestible nutrients, therefore, are considered as an excellent livestock feed. Field pea contains 5 to 20% less of the trypsin inhibitors than soybean. (Schatz and Endres, 2003). Green seeds are rich in Vitamin C,  $\beta$ -carotene, K, Fe, Mg, Ca, Fe and Zn (Table 8).

**Table 7.** The chemical composition and nutritive value of edible portion of raw, split, and mature seeds of pea

Nutrient	Value per 100 g
Proximates	
Energy	1425.00 kJ
Protein	24.55 g
Total lipid (fat)	1.16 g
Ash	2.65 g
Carbohydrate, by difference	60.37 g
Fiber, total dietary	25.50 g
Sugars, total	8.00 g
Minerals	
Calcium	55.000 mg
Iron	4.430 mg
Magnesium	115.000 mg
Phosphorus	366.000 mg
Potassium	981.000 mg
Sodium	15.000 mg
Zinc	3.010 mg
Copper	0.866 mg
Manganese	1.391 mg
Selenium	1.600 µg
Vitamins	
Vitamin C, total ascorbic acid	1.8 mg
Thiamin	0.726 mg
Riboflavin	0.215 mg
Niacin	2.889 mg
Pantothenic acid	1.758 mg
Vitamin B-6	0.174 mg
Folate, total	274.000 µg
Folic acid	0.00 µg
Folate, food	274.000 µg
Folate, DFE	274.000 µg DFE
Choline, total	95.500 mg
Vitamin A, RAE	7.000 µg RAE
Carotene, beta	89.000 µg
Vitamin A, IU	149.000 IU
Vitamin E (alpha-tocopherol)	0.090 mg
Tocopherol, gamma	2.090 mg



Nutrient	Value per 100 g
Tocopherol, delta	0.090 mg
Vitamin K (phylloquinone)	14.500 µg
Lipids	
Fatty acids, total saturated	0.161 g
Cholesterol	-
Phytosterols	135.000 mg
Amino acids	
Tryptophan	0.275 g
Threonine	0.872 g
Isoleucine	1.014 g
Leucine	1.760 g
Lysine	1.772 g
Methionine	0.251 g
Cystine	0.373 g
Phenylalanine	1.132 g
Tyrosine	0.711 g
Valine	1.159 g
Arginine	2.188 g
Histidine	0.597 g
Alanine	1.080 g
Aspartic acid	2.896 g
Glutamic acid	4.196 g
Glycine	1.092 g
Proline	1.014 g
Serine	1.080 g

Source: USDA National Nutrient Database for Standard Reference, Release 23 (2010) ([http://www.nal.usda.gov/fnic/foodcomp/cgi-bin/list\\_nut\\_edit.pl](http://www.nal.usda.gov/fnic/foodcomp/cgi-bin/list_nut_edit.pl))

**Table 8.** Chemical composition and nutritive value of raw green pea. Values in parenthesis indicate their percentage in green seeds

Constituent	Nutritional value per 100g
Energy	81.0 k cal
Carbohydrates	14.5 g
Sugar	5.7 g
Dietary fibre	5.1 g
Fat	0.4 g
Protein	5.4 g
Vitamin A	38.0 µg (4%)
β-carotene	449.0 µg (4%)
Lutein and Zeaxanthin	2593.0 µg
Vitamin B1	0.3 mg (23%)
Vitamin B2	0.1 mg (7%)
Vitamin B3	2.1 mg (14%)
Vitamin B5	0.1 mg (2%)
Vitamin B6	0.2 mg (15%)
Vitamin B9	65.0 µg (16%)
Vitamin C	40.0 mg (67%)
Calcium	25.0 mg (3%)
Iron	1.5 mg (12%)
Magnesium	33.0 mg (9%)
Phosphorus	108.0 mg (15%)
Potassium	244.0 mg (5%)
Zinc	1.2 mg (12%)

Source: USDA National Nutrient Database for Standard Reference, Release 23 (2010) ([http://www.nal.usda.gov/fnic/foodcomp/cgi-bin/list\\_nut\\_edit.pl](http://www.nal.usda.gov/fnic/foodcomp/cgi-bin/list_nut_edit.pl))

### Cultivation and Nutrient Requirement

Field peas can be grown in soils ranging from light sandy to heavy clay. They are less tolerant to salinity and highly susceptible to waterlogging and frost. It is a leguminous crop and has ability to fix atmospheric nitrogen. Generally there is no need to inoculate seeds with *Rhizobium* as soil contains them for effective nodulation. Peak nodule number is observed during mid vegetative stage of the crop growth which further increase in size and the maximum nodule size and nitrogen fixation ability is observed at the time of onset of flowering. While at fruiting there is severe degeneration in nodules (Pate, 1975). Nodulation is very sensitive to stresses as waterlogging, extremes of temperatures, low soil pH and poor light intensity retards nodule formation (Diener, 1950; Lie, 1969). Crop is moderately tolerant to soil salinity.



Like other legume crops, pea also responds to phosphorus, calcium, and potassium fertilizers. Plants also respond to boron and molybdenum. Manganese deficiency causes 'marsh spot' disease in pea.

Increased application of inorganic nitrogenous fertilizers reduces nodule formation as well as nitrogen fixation by nodules and higher doses of fertilizers totally suppress nitrogen fixation (Oghoghorie, 1971; Oghoghorie and Pate, 1971). Jensen (1987) reported that the application of fertilizer-N inhibited the rate of  $N_2$  fixation only during that period of growth, when the main part of fertilizer-N was taken up and shortly after that. Total accumulation of fixed nitrogen was estimated to be 244, 238 and 213 kg N ha<sup>-1</sup> in pea supplied with nil, 25 or 50 kg NO<sub>3</sub><sup>-</sup>-N ha<sup>-1</sup>, respectively. About one-fourth of total  $N_2$  fixation is reported to be carried out during preflowering, one fourth during the two weeks of flowering and the remainder during post-flowering. About 55% of the amount of N present in pods at maturity was estimated to be derived from mobilization of N from vegetative organs. Jensen (1987) also observed that in genotype "Starter" application @ 25 of N or 50 kg NO<sub>3</sub><sup>-</sup>-N ha<sup>-1</sup>) did not significantly influence either dry matter and nitrogen accumulation or the development of leaf area. Neither root length and root biomass, determined 8 weeks after seedling emergence nor the yield of seed dry matter and nitrogen at maturity were found to be affected by fertilizer application. However, Waterer *et al.*, (1992) observed that peas grown in the presence of low concentrations of NH<sub>4</sub><sup>+</sup> had significantly greater nodule numbers (up to 4-fold) than those grown without NH<sub>4</sub><sup>+</sup>. Nodule dry weight per plant was significantly higher at 14, 21 and 28 days after sowing (DAS) in plants grown in the presence of NH<sub>4</sub><sup>+</sup>, but individual nodule mass was lower than in plants grown without NH<sub>4</sub><sup>+</sup>. The nodulation pattern of the plants supplied with NH<sub>4</sub><sup>+</sup> was similar to that often reported for supernodulating mutants; however, the plants did not express other growth habits associated with supernodulation. Estimates of  $N_2$  fixation indicated that the plus-NH<sub>4</sub><sup>+</sup> plants fixed as much or more  $N_2$  than the plants supplied with minus-NH<sub>4</sub><sup>+</sup> nutrient solution. There were no significant differences in nodule number, nodule mass or NH<sub>4</sub><sup>+</sup> uptake between the plants grown at the two concentrations of NH<sub>4</sub><sup>+</sup>. Nodulation appeared to be autoregulated by 14 DAS in the minus-NH<sub>4</sub><sup>+</sup> treatment. Plant growth and N accumulation in the minus-NH<sub>4</sub><sup>+</sup> plants lagged behind those of the plus-NH<sub>4</sub><sup>+</sup> treatments prior to  $N_2$  fixation, becoming well established in the final week of the experiment. It is concluded that plus-NH<sub>4</sub><sup>+</sup> treatments did not elicit autoregulation and plants continued to initiate nodules throughout the experiment.

The estimated rate of  $N_2$  fixation in pea gradually increased during the pre-flowering and flowering growth stages and reached a maximum of 10 kg N fixed per ha per day nine to ten weeks after seedling

emergence, i. e., the period which coincides with early pod-development (flat pod growth stage) and also the time for maximum crop growth rate and maximum green leaf area index. A steep drop in  $N_2$  fixation rate has been observed during the following week. This drop is found to be simultaneous with lodging of the crop, pod-filling (round pod growth stage) and the initiation of mobilization of nitrogen from vegetative organs (Jensen, 1987).

Pea is a  $C_3$  plant. Photosynthesis is rather unaffected between temperature ranges of 25-35°C. Under normal environmental conditions photosynthesis is saturated at a light intensity of 17.6 k lux. The  $CO_2$  compensation point is around 70 ppm at saturation light intensity and 27°C (Pate, 1975). It is reported that in a nodulated pea plant during preflowering stage nearly 47% of the carbon transported from shoot to roots is lost by root respiration, 16% is used for root growth (including 6% for nodule growth), and nearly 20% is retranslocated to the shoot (Minchin and Pate, 1973).

### Source and Sink Relationship

In peas two phases of pod growth has been reported. The first one from anthesis to 18 days represents the main phase of fruit walls growth and the early growth of seeds, while the second one i. e., 18-36 days after anthesis, covers the maturation and senescence life of pod, and during later phase accumulation of food reserves in the contained seeds takes place (Flinn and Pate, 1968; Flinn *et al.*, 1977; Srivastava, 1981). During early phase, there is an increase in length, breadth, thickness and fresh weight of fruit walls. Nearly half of its dry matter of pod is accumulated in this phase. Afterwards, fruit walls lose dry matter and nitrogen steadily, and chlorophyll content and photosynthetic capacity is lost rapidly (Flinn and Pate, 1970). In the second half of the pod development period seeds incorporate nearly 86% of carbon acquired by the pods. Seeds exhibit a leveling off, if not a decline, in fresh weight, on approaching maturity. Decreased weight due to loss of water in the later phase of seed growth is compensated by the deposition of more reserve materials in the cotyledons (Smith, 1973).

The situation regarding carbon nutrition of seeds and fruit walls is quite obvious. Carbon assimilated in the early life cycle of the plant has no direct relevance to the pod maturation. Carbon fixed during reproductive phase supplied most of the carbon required for seed development. Carbon fixed during pre flowering phase is lost in respiration and most of the remaining assimilate is incorporated in such components/constituents which can not be mobilized (Pate and Flinn, 1973). In pea leaf, stipules and fruit walls born on the fruiting node are photosynthetically active. Varieties with equal leaf area are reported to



yield equally (Chauhan, 1970). However, partial defoliation of the leaflets at the node subtending the pod decreases the number of seeds per pod, but it has no effect on seed size (Chauhan, 1970), or marginally increased it (Srivastava, 1981). Rediotracer studies have revealed that stipules make a lesser contribution to the subtended pod than the companion leaflets and fruit walls. During early phase of pod development, major part of seed requirement for assimilates is fulfilled by the subtending leaf, while in later stages contribution from fruit walls is increased (Srivastava and Bhardwaj, 1986; Bhardwaj and Karivarathraju, 1972). It is because of the fact that as compared to leaflets, stipules transport more assimilates up and down the subtended node. It is reported that stipules have less direct vascular connections with the subtending pod stalk than the leaflets (Pate and Flinn, 1973; Bhardwaj and Karivarathraju, 1972; Srivastava and Bhardwaj, 1986). Short-term feeding of individual leaves with  $^{14}\text{CO}_2$  (Carr and Pate, 1967) or  $^{15}\text{NO}_3^-$  (Oghoghorie and Pate, 1972) confirmed that the links between the leaves of same vertical series are of great importance in assimilate transfer than are any connection with leaves on the opposite sides on them. Nearly 50 to 90% of the fed  $^{32}\text{P}$  moves to pod if the leaf at the pod bearing node is fed (Linck and Swanson, 1960; Lipavsky and Patr, 1976). Linck and Saudia (1962) further confirmed it using  $^{14}\text{C}$ . Relatively little (1%)  $^{14}\text{C}$  activity was traced in the roots and about 9% in stem and leaves. They observed sucrose to be accumulated in leaves and expected that sucrose is the form in which photosynthates are translocated to the pods.

Leaf and fruit walls at the lowest reproductive node provide approximately 2/3 of the carbon required by the seeds ripening at that node. Leaflets and stipules of this node contribute nearly 174 and 74 mg carbon to the seeds. Nearly 85% of this is constituted by currently fixed carbon, and the remaining by the remobilization of pre-flowering stage fixed carbon (Pate and Flinn, 1973). Pate (1975) observed that the pattern of inter-connections with in vascular system of pea stem corresponds to the vascular system in *Trifolium* as proposed by Devadas and Beck (1972), where four axial vascular bundles (designated as  $A_1$ ,  $A_2$ ,  $A_3$ ,  $A_4$ ) run through out the stem, and in a definite sequence give rise to lateral traces supplying the organs of specific nodes. Two of these axial bundles connect to leaves in an alternate manner, i.e.  $A_1$  links with leaf at nodes 2, 4, 6 etc., while  $A_4$  links with the leaf at 1, 3, 5 etc. bundles  $A_2$  and  $A_3$  are not directly linked to leaves. Therefore, there are direct but unilateral vascular connections between specific leaves on the alternately branched stem (i.e.  $\frac{1}{2}$  phyllotaxy). The vascular supply to stipules is more complex. At any node the stipules are linked to each of the three axial bundles which do not connect directly to the subtending leaf.

It was observed that pod gas cavity contains high concentration of  $\text{CO}_2$  (0.15 to 1.5%  $\text{CO}_2$  v/v) (Flinn *et al.*, 1977). Inner, the chloroplast containing, epidermal lining of pod gas cavity is actively involved in



photoassimilation of  $\text{CO}_2$  released from respiring seeds. This layer has also high activity of RuBISCO and PEP-carboxylase. As compared to the inner epidermal layer, outer photosynthetic layer of pod has lower rate of photosynthesis as well as lower activity of carboxylating enzymes (Atkins *et al.*, 1977). Genotypic differences in the level of carboxylating enzymes are reported in peas. Yellow coloured pods exhibit high PEP-carboxylase activity, while green ones contain high RuBP-carboxylase activity (Price and Hardley, 1980).

Fruit walls photosynthetic rate in peas varies with the age of pod and the concentration of  $\text{CO}_2$  in the atmosphere. Assimilation rate is the maximum during extension growth period of the pod, which decreases later on. The  $\text{CO}_2$  compensation point of pod increases from 150 ppm to more than 550 ppm with advancement in pod age (Harvey *et al.*, 1976).

Seeds are reported to be incapable of fixing  $\text{CO}_2$  either in light or in dark at all developmental stages (Bhardwaj and Karivarathraju, 1972; Flinn *et al.*, 1977).

Varietal differences in accumulation of reserve materials have been observed. At 16 days after anthesis stage, when expressed on per unit dry weight of seed, variety Mahndorfer accumulated more reducing sugar than genotype Vares, while at 27 days stage accumulation of reducing sugar was more in Vares. At maturity Mahndorfer contained more reducing sugars than Vares. Starch accumulation in both the varieties started after 16 days following anthesis. Mahndorfer had more starch than Vares. The seed size was also bolder in Mahndorfer (Nath, 1972). At early stage of seed development, accumulation of protein is at a slow pace; however, this phase is followed by a phase of rapid protein synthesis and storage in seeds. In the final phase, i. e., approaching seed maturity, only protein synthesis continues, that too with a very slow rate (Chatterjee *et al.*, 1978). Low amount of protein and high starch content has been reported in seeds produced from early flowering types (Jaiswal *et al.*, 1975; Odoardi *et al.*, 1976).

The onset of flowering and subsequent growth in pea leads to a rapid doubling of photosynthesis of whole plant (Lawrie and Wheeler, 1975). In cultivar Onward, three well distinct peaks for the demand of assimilate has been observed, the first one during rapid elongation of pod; second during inflation growth of pod; and the third peak during rapid growth of the seeds and the leaflet photosynthetic rate is regulated by these demands during pod development (Flinn, 1974). However, Srivastava (1981) observed that peak of net photosynthetic rate in leaves and the growth of subtending pods are not synchronous, and occur at different periods. Perhaps photosynthetic rate of leaf is under control of other sinks too viz., roots and nodules. Pod is a provider of photosynthates to the contained seeds, as if seeds are removed and fruit walls are fed with  $^{14}\text{CO}_2$ , radioactivity is exported out of fruit walls (Pate, 1975).



The rate of  $^{14}\text{CO}_2$  export from pea leaf is increased significantly if all other leaves are removed from shoot. However, if root and shoot apices are also removed at the time of defoliation, such effect is not observed (Lovell *et al.*, 1972). Higher seed size in pea is reported to be related to rate of photosynthates flow to the pod, and to the capacity of seeds to accumulate them, rather than by the capacity the subtending leaf to fix  $^{14}\text{CO}_2$  (Srivastava and Bhardwaj, 1987).

Pea genotypes having higher pod number per plant also yield higher. The number of seed per pod and seed size is governed by growth pattern of developing pod, which, in turn, is governed by the contributions made by the photosynthesizing organs subtending the pod bearing node (Srivastava, 1981).

A range of auxin like compounds, including 4-chloroindol-3 yl acetate (Marumo *et al.*, 1968) and D-4-chlorotryptophan derivatives (Marumo and Hattori, 1970) have been isolated from immature seeds of pea.

It is reported that developing seeds synthesize gibberellic acid (Baldev *et al.*, 1965; Roper *et al.*, 1978). Presence of  $\text{GA}_9$ ,  $\text{GA}_{17}$ ,  $\text{GA}_{20}$  and  $\text{GA}_{29}$  has been reported in developing pea seeds (Eeuwens *et al.*, 1973). Amount of  $\text{GA}_{29}$  in seeds and fruit walls was found to be the maximum during initial phase of pod development, and lowest at maturity (Durley *et al.*, 1979; Nath, 1972; Srivastava, 1981).

Three maxima in the level of endogenous cytokinin content of developing seeds; first timed with the attainment of the maximum volume of liquid endosperm in the seed, and the other two maxima synchronizing with the maximum rate of growth of seed and the embryo, are reported. During lag period of seed growth, decrease in endogenous cytokinin is reported (Burrow and Carr, 1970; Bruinsma, 1977). Seeds are having the ability to synthesize cytokinins (Hahn *et al.*, 1974); however, this was contradicted by Van Staden and Button (1978). Cytokinin level in seeds is always higher than that in fruit walls (Krechting *et al.*, 1978). Genotypic differences in the seed and fruit walls cytokinin contents have been reported (Nath, 1972; Srivastava, 1981). In pea, positive correlation has been observed between seed size and endogenous levels of auxin and cytokinin like substances in seed (Srivastava, 1981).

Absciscic acid has been characterized in the chloroplasts of pea (Railton *et al.*, 1974), presence of absciscic acid in developing seeds and fruit walls of pea has been clearly visualized (Browning, 1980; Srivastava, 1981). The maximum concentration of absciscic acid in fruit walls and contained seeds has been observed during senescence of pod (Srivastava, 1981).

The effects of water deficit and high temperature on the production of  $\alpha$ -amylase inhibitor ( $\alpha$ -AI-1), a compound that has ability to control the seed-feeding pea weevil (*Bruchus pisorum* L., Coleoptera: Bruchidae) was studied (de Sousa-Majer, 2004) in transgenic and non-transgenic pea

plants. Plants were subjected to water deficit and high temperature treatments under controlled conditions in the glasshouse and growth cabinet, beginning 1 week after the first pods were formed. In the water deficit treatments, the peas were either adequately watered (control) or water was withheld after first pod formation. The high temperature experiments were performed in two growth cabinets, one maintained at 27/22 °C (control) and one at 32/27 °C day/night temperatures, with the vapour pressure deficit maintained at 1.3 kPa. The plants exposure to high temperatures and water deficit produced 27% and 79% fewer seeds, respectively, than the controls. In the transgenic peas the level of  $\alpha$ -AI-1 as a percentage of total protein was not influenced by water stress, but was reduced on average by 36.3% in the high temperature treatment. Transgenic and non transgenic pods of plants grown at 27/22 °C and 32/27 °C were inoculated with pea weevil eggs to evaluate whether the reduction in level of  $\alpha$ -AI-1 in the transgenic pea seeds affected pea weevil development and survival. At the higher temperatures, 39% of adult pea weevil emerged, compared to 1.2% in the transgenic peas grown at the lower temperatures. Thus, they concluded that high temperature reduces the protective capacity of the transgenic peas from weevil.

Major constraints in pea production are the susceptibility of crop to frost and powdery mildew. Development of varieties devoid of leaflets has improved the production since such genotypes are not damaged by powdery mildew. Tendrils also form a network in the crop canopy which prevents crop damage from birds.

## REFERENCES

- Addis, G. and Narayan, R. K. J. 1994. Developmental variation of the neurotoxin,  $\beta$ -N-oxalyl-L- $\alpha$ ,  $\beta$ -diamino propionic acid (ODAP), in *Lathyrus sativus*. *Annals Bot.* **74**: 209-15.
- Adrian, A.; Franke, L. J.; Custer, C. M. C. and Norala, K. K. 1994. Quantification of phytoestrogen in legumes by HPLC. *J.F. Agric. Food Chem.* **42**: 1905-13.
- Adsule, R. N.; Kadam, S. S. and Leung, H. K. 1989. Lentil. In: *CRC Handbook of World Food Legumes: Nutritional Chemistry, Processing Technology, and Utilization*. Salunkhe D. K. and Kadam S. S., (Eds). CRC Press, Boca Raton, FL, **2**: 133-152.
- Ahlawat, I. P. S. <http://nsdl.niscair.res.in/bitstream/123456789/508/1/FRENCH+BEANS-+formatted.pdf>
- Andrews, M. and McKenzie, B. A. 2007. Adaptation and ecology. In: *Lentil: An ancient crop for modern time*. Yadav S. S., McNeil D. and Stevensen P. C., (Eds). Springer, pp. 23-32.
- Anonymous 2000. IPGRI 2000.** In: An Introduction to Lathyrus. <http://www.cgiar.org/igpri/>



- Atkins, C. A.; Kuo, J.; Pate, J. S.; Flinn, A. M. and Steele, T. W. 1977. Photosynthetic pod wall of pea (*Pisum sativum* L.): Distribution of carbon dioxide fixing enzymes in relation to pod structure. *Plant Physiol.* **57**: 17-20.
- Awolunate, E. O. 2006. Accumulation and quality of storage protein in developing cowpea, mung bean and soya bean seeds. *J. Sci. Food Agric.* **34**: 1351 – 35.
- Bains, T. S.; Singh, S.; Singh, I. and Gill R. K. 2007. Breeding for ideal plant type in spring/summer mungbean. *In: I International Conference on Indigenous Vegetables and Legumes*. Prospects for Fighting Poverty, Hunger and Malnutrition. Chadha M. I., Kuo G. and Gowda C. C. L., (Eds). *ISHS Acta Hort.* 752.
- Baldev, B.; Lang, A. and Agatep, A. O. 1965. Gibberelline production in pea seeds developing in excised pods: Effect of growth retardant AMO-1618. *Science.* **147**: 155-57.
- Beebe, S.; Rao, I.; Blair, M. W. and Butare, L. 2009. Breeding for abiotic stress tolerance in common bean: Present and future challenges. *In: Proceedings. Global Partnership Initiative for Plant Breeding Capacity Building (GIPB)*. Australian Plant Breeding: SABRAO Conference (14; 11; 2009, Cairns, Queensland, Australia). Queensland Australia. pp. 11
- Begum, A.; Ahmad, A.; Kaisar, M. O.; Islam, M. M. and Anam, M. K. 2003. Morphological and reproductive attributes in french bean (*Phaseolus vulgaris*) as influenced by sowing time and fertilizer treatment. *Pakistan J. Biol. Sci.* **6**: 1902-1906.
- Bhardwaj, S. N. and Karivarathraju, T. V. 1972. Translocation of photosynthates from fruit walls and leaves during development of field peas (*Pisum arvensis* L.). *Indian J. Plant Physiol.* **15**: 38-55.
- Bhattacharya, A. 2009. Yield determination in lentil under non-irrigated and irrigated conditions: Phenology, dry matter distribution and yield attributes. *Indian J. Agric. Res.* **43**: 1-9.
- Bhattacharya, A. and Vijaylakshmi. 2005. Genetic diversity in mungbean: Phenological, physiological and yield forming traits. *Legume Res.* **28**: 1-6.
- Bhivare, V. N. and Nimbalkar, J. D. 1984. Salt stress effect on growth and mineral nutrition of French beans. *Plant Soil.* **80**: 91-98.
- Bisht, I.; Bhat, K.; Lakhanpaul, S.; Latha, M.; Jayan, P.; Biswas, B and Singh, A. 2005. Diversity and genetic resources of wild *Vigna* species in India. *Genetic Resources Crop Evolution.* **52**: 53-68.
- Bisht, I.; Mahajan, R. and Patel, D. 1998. The use of characterization data to establish the Indian mungbean core collection and assessment of genetic diversity. *Genetic Resources Crop Evolution* **45**: 127-33.
- Browning, G. 1980. Endogenous cis, trans-abscisic acid and pea (*Pisum sativum* cv. Dark Skin Perfection) seed development: Evidence for a role in seed growth from changes induced by temperature. *J. Exp. Bot.* **31**: 185-98.

- Bruinsma, J. 1977. Role of cytokinin in flower and fruit development. *Z. Pflanzen. Bodenkd.* **140**: 15-23.
- Burrow, W. J. and Carr, D. J. 1970. Cytokinin content of pea seeds during their growth and development. *Physiol. Plant.* **23**: 1064-70.
- Bushby, H. and Lawn, R. 1992. Accumulation and partitioning of dry matter by contrasting genotypes of mungbean (*Vigna radiata* (L.) Wilczek). *Aust. J. Agric. Res.* **43**: 1609-28.
- Campbell, C. G. 1997. Grass pea *Lathyrus sativus* L. Promoting the conservation and use of underutilized and neglected crops. 18. Institute of Plant Genetic and Crop Plant Research, Gatersleben/International Plant Genetic Resources Institute, Rome, Italy, pp. 1-91.
- Campbell, C. G.; Mehta, R. B.; Agrawal, S. K.; Chen, Y. Z.; Adb El Moneim, A. M.; Khawaja, H. I. T.; Yadov, C. R.; Tay, J. U. and Araya, W. A. 1994. Current status and future strategy in breeding grasspea (*Lathyrus sativus*). *Euphytica* **73**: 167-75.
- Carr, D. J. and Pate, J. S. 1967. Ageing of whole plant. *Symp. Soc. Exp. Biol.* **21**: 559-600.
- Chaib, S. L.; Bulisami, E. A. and Castro, L. H. M. S. 1984. Growth and yield of beans as affected by depth of phosphate fertilizer application. *Pesquisa Agropecudria Brasileira.* pp. 817-22.
- Chandra, S.; Yadav, A. K. and Sagar, P. 1977. Growth attributes in mungbean. *Indian J. Gent. Plant Breeding.* **37**: 415-19.
- Chase, R. A.; Pearson, S.; Nunn, P. B. and Lantos, P. L. 1985. Comparative toxicity of  $\alpha$ - and  $\beta$ -N-oxaly1-L- $\alpha$ ,  $\beta$ -diaminopropionic acid to rat spinal cord. *Neuriosci. Lett.* **55**: 89-94.
- Chatterjee, A.; Pokhriyal, T. C. and Abrol, Y. P. 1978. Changes in the content of protein and amino acids in developing pea (*Pisum sativum*) seeds. *Plant Biochem. J.* **5**: 69-76.
- Chauhan, D. S. 1970. Physiological analysis of varietal differences in seed yield in field peas (*Pisum arvensis* L.). M. Sc. Thesis, PG School, IARI, New Delhi.
- Chinnasamy, G. and Bal, A. K. 2003. The pattern of seed development and maturation in beach pea (*Lathyrus maritimus*). *Canadian J. Bot.* **81**: 531-40.
- Chopra, J.; Kaur, N. and Gupta, A. K. 2000. Ontogenic changes in enzymes of carbon metabolism in relation to carbohydrate status in developing mungbean reproductive structures. *Phytochem.* **53**: 539-48.
- Chopra J.; Kaur, N. and Gupta, A. K. 2003. Changes in the activity of carbon metabolizing enzymes with pod development in lentil (*Lens culinaris* L.). *Acta Physiol. Plant.* **25**: 185-91.
- Chopra, J.; Kaur, N. and Gupta, A. K. 2005a. Activities of sucrolytic enzymes



in developing pods of lentil genotypes differing in seed size. *Acta Physiol. Plant.* **27**: 89-93.

Chopra, J.; Kaur, N. and Gupta, A. K. 2005b. Role of enzymes of sucrose-starch conversion in seed sink strength in mung bean. *Biol. Plant.* **49**: 561-66.

Clifford, P. E. 1979, Source limitation of sink yield in mung bean. *Ann. Bot.* **43**: 397-99.

Cole, S. 1961. Neolithic Revolution. 2<sup>nd</sup> edition. London. British Musium (Natural History).

Curran, W. S.; Morrow, L. A. and Whitesides, R. F. 1987. Lentils (*Lens culinaris*) yield as influenced by duration of wild oat (*Avena fatua*) interference. *Weed Sci.* **35**: 669 - 72.

Dahiya, B. S. 1976. Seed morphology as an indicator of low neurotoxin in *Lathyrus sativus* L. *Plant Food Humen Nutrition.* **25**: 391-94.

Dahiya, B. S. and Jeswani, L. M. 1975. Genotype x environment interactions for neurotoxic principle (BOAA) in grass-pea. *Indian J. Agric. Sci.* **45**: 437-39.

Das, P. K.; Kundagrami, S. and Saha, K. C. 2001. Pattern of nodulation and biological nitrogen fixation in grasspea (*Lathyrus sativus* L.) genotypes. *Indian J. Gen. Plant Breeding.* **61**:

De Costa, W. A. J. M.; Shanmugathan, K. N. and Joseph, K. D. S. M. 1999. Physiology and yield determination of mung bean (*Vigna radiata* (L.) Wilczek) under various irrigation regimes in the dry and intermediate zones of Sri Lanka. *Field Crop Res.* **61**: 1-12.

De Sousa-Majer; Maria, J.; Turner, N. C.; Hardie, D. C.; Morton, R. L.; Lamont, B. and Higgins, T. J. V. 2004. Response to water deficit and high temperature of transgenic peas (*Pisum sativum* L.) containing a seed specific  $\alpha$ -amylase inhibitor and a subsequent effects on pea weevil (*Bruchus pisorum* L.) survival. *J. Exp. Bot.* **55**: 497-505.

Department of Agriculture and Food. Govt. Western Australia. Crops. <http://www.agric.wa.gov.au>.

Devadas, C. and Beck, C. B. 1972. Comparative morphology of the primary vascular systems in some species of Rosaceae and Leguminosae. *Amer J. Bot.* **59**: 557-67.

Dhiman T. R.; Sharma, V. K. and Narang, M. P. 1983. Evaluation of 'Khesari dhal' (*Lathyrus sativus*) in calf starter. *Agric. Wastes.* **8**: 1-8.

Diener, T. 1950. Über die Bedingungen der Wurzelknöllchenbildung bei *Pisum sativum* L. *Phytopath. Z.* **16**: 129-70.

Dixit, S.; Khanna, S. K. and Das, M. 2008. Non-uniform implementation of ban on *Lathyrus* cultivation in Indian states leading to unwanted exposure to consumers. *Current Sci.* **94**: 570-72.

Durley, R. C.; Sassa, T. and Pharis, R. P. 1979. Metabolism of tritiated gibberelline

- A<sub>20</sub> in immature seeds of dwarf pea cv. Meteor. *Plant Physiol.* **64**: 214-19.
- Eeuwens, C. J.; Gaskin, P. and MacMillan, J. 1973. Gibberelline A<sub>20</sub> in seeds of *Pisum sativum* L. cv. Alaska. *Planta.* **115**: 73-76.
- Egli, D. and Bruening, W. 2002. Fruit development and reproductive survival in soybean: Position and age effects. *Field Crop Res.* **98**: 195-202.
- Erskine, W. 1996. Seed size effect on lentil (*Lens culinaris*) yield potential and adaptation to temperature and rainfall in West Asia. *J. Agric. Sci.* **126**: 335-41.
- Erskine, W.; Muehlbauer, F.; Sarker, A. and Sharma, B. 2009. Introduction. In: *The Lentil: Botany, Production and Uses*. Erskine W., Muehlbauer F., Sarker A. and Sharma B., (Eds). CAB International, USA, pp. 1-3.
- FAO: Economic and Social Department: The Statistical Division
- Ferguson, M. E. and Robertson, L. D. 1999. Morphological and phenological variation in the wild relatives of lentils. *J. Genetis Resource Crop Evolution*: **46**: 3-12.
- Fery, R. L. 2002. New opportunities in Vigna. In: *Trends in New Crops and New Uses*. (J. Janick, A. Whipkey, eds.). ASHS Press, Alexandria, VA, pp. 424-428.
- Field Peas. [http://www.harvestwizard.com/2007/04/field\\_peas\\_field\\_peas\\_are.html](http://www.harvestwizard.com/2007/04/field_peas_field_peas_are.html)
- Flinn, A. M. 1974. Regulation of leaflet photosynthesis by developing fruit in pea. *Physiol. Plant.* **31**: 275-78.
- Flinn, A. M. and Pate, J. S. 1968. Biochemical and physiological changes during maturation of field peas (*Pisum sativum* L.). *Ann. Bot.* **32**: 479-95.
- Flinn, A. M. and Pate, J. S. 1970. A quantitative study of carbon transfer from pod and subtending leaf to the ripening seeds of the field pea (*Pisum arvense* L.). *J. Exp. Bot.* **21**: 71-82.
- Flinn, A. M.; Atkins, C. A. and Pate, J. S. 1977. Significance of photosynthetic and respiratory exchange in the carbon economy of developing pea fruits. *Plant Physiol.* **60**: 412-18.
- Ganapathy, K. T. and Dwivedi, M. P. (1961). Studies on clinical epidimology of *Lathyrus*. Rewa, Indian Council of Medical Research.
- Grela, E. R.; StudziŃski, T. and Matras, J. 2001. Antinutritional factors in seeds of *Lathyrus sativus* cultivated in Poland. *Lathyrus Lathyrism Newsletter.* **2**: 101-104.
- Grela, E. R.; StudziŃski, T. and Winiarska, A. 2000. Lathyrism in people and animals. *Med. Wet.* **56**: 558-62.
- Hahn, H.; Zacks, R. De. and Kende, H. 1974. Cytokinin formation in pea seeds. *Naturwissenschaften.* **61**: 170.
- Hamid, A.; Hashem, A.; Hamid, A.; Miah, A. A. and Nag, B. L. 1995. Seed development, quality, maturity synchrony and yield of selected mungbean genotypes. *Seed Sci. Tech.* **23**: 761-70.



- Hanbury, C. D.; Siddique, K. H. M.; Galwey, N. W. and Cocks, P. S. 1999. Genotype environment interaction for seed yield and ODAP concentration of *Lathyrus sativus* L. and *L. cicera* L. in Mediterranean type environment. *Euphytica*, **110**: 45-60.
- Hanbury, C. D.; White, C. L.; Mullan, B. P. and Siddique, K. H. M. 2000. A review of the potential of *Lathyrus sativus* L. and *L. cicera* L. grain for use as animal feed. *Anim. Feed Sci. Tech.* **87**: 1-27.
- Haqqani, A. M. and Pandey, R. K. 1994. Response of mungbean to water stress and irrigation at various growth stages and plant densities: II. Yield and yield components. *Tropical Agric.* **71**: 289-294.
- Harvey, D. M. 1976. Carbon di oxide photoassimilation in normal-leaved and mutant forms of *Pisum sativum* L. *Ann. Bot.* **36**: 981-991.
- Hytowitz, D. B. and Matthews, R. H. 1986. Composition of Foods: Legumes and Legume Products. Agriculture Handbook No. 8-16. Washington, DC. US Department of Agriculture.
- Ignacimuthu, S. and Babu, C. R. 1987. *Vigna radiata* var. *sublobata* (Fabaceae): Economically useful wild relative of urd and mung beans. *Econ. Bot.* **41**: 418-422.
- IIPR. 2009. AICRP MULLaRP (IIPR Kanpur). Nov. 17. 2009. <http://www.iipr.res.in/mullarp.htm>
- Imrie, B. C. 1983. Response to selection for weathering resistance in mungbean. In: Proc. 8<sup>th</sup> Australian Plant Breeder Conference. Driscoll C. J., (Ed.). University of Adelaide, Adelaide, Australia, pp. 298-99.
- Imrie, B. C. 1996. Mung bean. In: *The New Rural Industries. A Handbook for Farmers and Investors*. Hyde K., (Ed.). Rural Industries Research and Development Corporation, Canberra, Australia, pp. 355-60.
- Imrie, B. C. and Lawn, R. J. 1990. Time to flowering of mung bean (*Vigna radiata*) genotypes and their hybrids in response to photoperiod and temperature. *Exp. Agric.* **26**: 307-18.
- Interactive Agricultural Ecological Atlas of Russia and Neighboring Countries. Economic plants and their diseases, pests and weeds. *Lathyrus sativus* L. - Grass Pea. [http://www.agroatlas.spb.ru/en/content/cultural/Lathyrus\\_sativus\\_K/](http://www.agroatlas.spb.ru/en/content/cultural/Lathyrus_sativus_K/)
- Introduction: Lentils. <http://www.icarda.org/Publications/Cooks/Lentil/Lentil.html>
- Jackson, M. T. and Yunus, A. G. 1984. Variation in the grass pea (*Lathyrus sativus* L.) and wild species. *Euphytica*. **33**: 549-59.
- Jain, A. K.; Sudhir Kumar and Panwar, J. D. S. 2007. Response of mungbean to phosphorus and micronutrients on N and P uptake and seed quality. *Legume Res.* **30**: 201-04.
- Jaiswal, S. P.; Kaur, G.; Kumar, J. C.; Nandpuri, K. S. and Thakur, J. C. 1975. Chemical constituents of green pea and their relationship with some plant characters. *Indian J. Agric. Sci.* **45**: 47-52.

- Jansen, P. C. M. 2006. *Vigna*. In: *Plant Resources of Tropical Africa I. Cereals and Pulses*. Brink M. and Belay G., (Eds). PROTA Foundation, Wageningen, Netherlands/Backhuys Publishers, Leiden, Netherlands/CTA, Wageningen, Netherlands. pp 206-08.
- Jensen, E. S. 1987. Seasonal patterns of growth and nitrogen fixation in field-grown pea. *Plant Soil*. **101**: 29-37.
- Katerji, N.; van Hoorn, J. W.; Hamdy, A.; Mastrorilli, M.; Oweis, T. and Erskine, W. 2001. Response of two varieties of lentil to soil salinity. *Agric. Water Management* **47**: 179-90.
- Katiyar, P. K.; Chandra, S.; Singh, B. B.; Dixit, G. P. and Ali, M. 1999. Characterization of mungbean varieties released in India. I. International Conference on Indigenous Vegetables and Legumes. Prospects for Fighting Poverty, Hunger and Malnutrition. ISHS *Acta Horticulture* 752. [www.actahort.org](http://www.actahort.org).
- Kaul, A. K.; Islam, M. Q. and Hamid, A. 1986. Screening of *Lathyrus* germplasms of Bangladesh for BOAA content and some agronomic characters. In: *Lathyrus and Lathyrism*. (A. K. Kaul and D. Combes, eds.). Third World Medical Research Foundation, New York. pp. 130-41.
- Keatinge, J. D. H.; Qi, A.; Kusmenoglu, I.; Ellis, R. H.; Summerfield, R. J.; Erskine, W. and Beniwal, S. P. S. 1996. Using genotypic variations in flowering responses to temperature and photoperiod to select lentil for the west Asian highlands. *Agric. Forest Met.* **78**: 53-65.
- Kislev, M. E. 1989. Origin of the cultivation of *Lathyrus sativus* and *L. cicera* (fabaceae). *Econ. Bot.* **43**: 262-70.
- Krechting, H. C. J. M.; Varga, M. and Bruinsma, J. 1978. Absence of cytokinin biosynthesis in pea seeds developing *in vitro*. *Z. Pflanzenphysiol.* **87**: 91-93.
- Krishnareddy, S. V. and Ahlawat, I. P. S. 2008. Growth and yield response of lentil cultivars to phosphorus, zinc and biofertilizers. *J. Agron. Crop Sci.* **177**: 49-59.
- Kumar, A. and Sharma, K. D. 2009. Physiological response and dry matter partitioning in summer mungbean (*Vigna radiata* L.) genotypes subjected to drought stress. *J. Agro. Crop Sci.* **195**: 270-277.
- Kumari, P. and Dahiya, B. S. 1981. Preliminary observations on production of hard seeds in green gram (*Vigna radiata* L.). In: *Second Workshop on Seed Technology*, HAU, Hisar, India.
- Kumari, V. and Prasad, R. 2005. Model plant type in Khesari (*Lathyrus sativus* L.) suitable for hill farming. *Lathyrus Lathyrism Newsletter* **4**: 15-17.
- Kuo, C. G.; Hsu, F. H.; Tsay, J. S. and Park, H. G. 1980. Variation in specific leaf weight and RuDPCase activity in mungbean. *Canadian J. Plant Sci.* **60**: 1059-62.



Kuo, C. J.; Wang, L. J.; Cheng, A. C. and Chou, M. H. 1978. Physiological basis of mungbean yield improvement. In: Proceedings of First International Mungbean Symposium Cowell, R. (Ed.). AVRDC. Taiwan, pp. 205-09.

Kuo, G. C. 1998. Growth, development, and physiological aspects of mungbean yield. *In: Multilocation Testing on Mungbean Germplasm Training Course: Lecture Handout*. Nakhon Pathom : Kasetsart University. AVRDC Staff Publication, pp. 188-93.

Kurdali, F.; Kalifa, K. and Al-Shamma, M. 1997. Cultivar differences in nitrogen assimilation, partitioning and mobilization in rain-fed lentil. *Field Crops Res.* **54**: 235-43.

Lal, M. S.; Agrawal, I. and Chitale, M. W. 1986. Genetic improvement of chickling vetch (*Lathyrus sativus* L.) in Madhya Pradesh, India. *In: Lathyrus and Lathyrism*. Kaul A. K. and Combes D., (Eds). New York: Third World Medical Research Foundation, pp. 146-66.

Lambein, F.; Haque, R.; Khan, J. K.; Kebede, N. and Kuo, Y. H. 1994. From soil to brain: Zinc deficiency increases the neurotoxicity of *Lathyrus sativus* and may affect the susceptibility for the motorneuron disease neurolathyrism. *Toxicon.* **32**: 461-66.

Lambrides, C. J. 1996. 'Breeding for improved seed quality traits in mungbean (*Vigna radiata* L. Wilczek) using DNA markers'. Ph. D. Dissertation, University of Queensland, Brisbane, Australia.

Lambrides, C. J. and Godwin, I. D. 2007. Mungbean. *In: Genome Mapping and Molecular Breeding in Plants*. Vol. 3. Pulses, Sugar and Tuber Crops. Kole C., (Ed.). Springer-Verlag, Berlin, Heidelberg, pp. 68-89.

Lathyrus Lathyrus. <http://en.wikipedia.org/wiki/lathyrusLathyrus>

Lawn, R. J. 1995. The Asiatic Vigna species. Vigna spp. (*V. radiata*, *V. mungo*, *V. angularia*, *V. umbellata* and *V. aconitifolia*) (Leguminosae-Papilionoideae). *In: Evolution of Crop Plants*. Smartt J., Simmonds N.W., (Eds). 2<sup>nd</sup> edition. Longman, London, pp. 321-26.

Lawn, R. J. and Ahn, C. S. 1985. Mung bean (*Vigna radiata* (L.) Wilczek/*Vigna mungo* (L.) Hepper). *In: Grain Legume Crops*. Summerfield R. J. and Roberts E. H., (Eds). William Collins Sons & Co. Ltd, London, pp. 584-623.

Lawrie, C. and Wheeler, C. T. 1975. The effect of flowering and fruit formation on the supply of photosynthetic assimilates to the nodule of *Pisum sativum* L. in relation to the fixation of nitrogen. *New Phytol.* **73**: 1119-28.

*Lens culinaris* Medik. <http://www.hort.purdue.edu/newcrop/afcm/lentil.html>

*Lens culinaris* Medik. <http://www.hort.purdue.edu/newcrop/CropFactSheets/lentil.html>

Lentil Facts & Lore. <http://www.lentilfest.com/DrawOnePage.aspx?PageID=6>

Lentils. Lentils information, history and recipies. <http://www.recipes4us.co.uk/>

[specials%20and%20holidays/Lentils%20Origin%20Uses%20Recipes.htm](#)

Leport, L.; Turner, N. C.; French, R. J.; Tennant, D.; Thomson, B. D. and Siddique, K. H. M. 1998. Water relation, gas exchange and growth of cool-season grain legumes in a Mediterranean-type environment. *European J. Agron.* **9**: 295-303.

Lie, T. A. 1969. The effect of low pH on different phases of nodule formation in pea plants. *Plant Soil.* **31**: 391-406.

Liener, I. E. and Kakade, M. L. 1980. Protease inhibitors. *In*: Toxic constituents of plant foodstuffs. Liener I. E., (Ed.). Academic Press, NY, pp. 7-71.

Linck, A. J. and Saudia, T. W. 1962. Translocation of labelled photosynthates from the bloom leaf node to the fruit of *Pisum sativum* L. *Experientia.* **18**: 69-70.

Linck, A. J. and Swanson, C. A. 1960. A study of several factors affecting the contribution of phosphorus-32 from the leaves of *Pisum sativum*. *Plant Physiol.* **12**: 57-68.

Lipavsky, J. and Patr, J. 1976. Contribution to the study of the translocation of phosphorus and assimilates from the leaves of pea (*Pisum sativum* L.). *Sbornik Vysoke' Skoly Zemedelske' V Praze Fakulta Agronomica'*. A No. 2. 155-65.

Lisiewska, Z.; Korus, A. and Kmiecik, W. 2003. Changes in chemical composition during development of grass pea (*Lathyrus sativus* L.) seeds. *Nahrung.* **47**: 391- 96.

Lovell, P. H.; Oo, H. T. and Sagar, C. R. 1972. An investigation into rate and control of assimilate movement in *Pisum sativum*. *J. Exp. Bot.* **23**: 255-66.

Marumo, S. and Hattori, H. 1970. Isolation of D-4-chlorotryptophane derivatives as auxin-related metabolites from immature seeds of *Pisum sativum*. *Planta.* **90**: 208-11.

Marumo, S.; Hattori, H.; Abe, H. and Munakata, K. 1968. Isolation of 4-chloro-3-acetic acid from immature seeds of *Pisum sativum*. *Nature* **219**: 959-60.

Mathur, V. L.; Laxmikant; Joshi, A. B.; Kant, L. and Joshi, A. 1998. Study of nodulation, leghaemoglobin content and NRA in black gram (*Vigna mungo* L. Hepper). *Legume Res.* **21**: 221-24.

McKenzie, B. A. and Hill, G. D. 2004. Water use in grain legumes. *In*: *Proceedings of the Fifth European Conference on Grain Legumes/Second International Conference on Legume Genomics and Genetics*. AEP-I'Association Européenne de Recherche sur les Protéagineuse, Paris. France, pp. 61-62.

McNeil, D. and Materne, M. 2007 Rhizobium management and nitrogen fixation. *In*: Lentil: an ancient crop for modern times. (S. S. Yadav, D. McNeil and P. C. Stevensen, eds.). Springer, pp. 127-43.

Meelu, O. P.; Singh, Y and Singh, B. 1994. Green manuring for soil productivity improvement. *World Soil Resources Reports.* 76 FAO Rome. pp. 123.



- Mehta, S. L.; Santha, I. M.; Yadav, V. K.; Roy, P. K. and Barat, G. K. 1991. Plant biotechnological approaches for elimination of oxalyl diaminopropionic acid neurotoxin from *Lathyrus sativus*. In: *Proceedings Golden Jubilee Celebrations Symposium on Grain Legumes*. Sharma B., (Ed.). *Indian Soc. Genetics Plant Breeding*, New Delhi, pp. 325-32.
- Minchin, F. R. and Pate, J. S. 1973. Carbon balance of a legume and the functional economy of its root nodules. *J. Exp. Bot.* **24**: 259-71.
- Ministry of Agriculture, Forest and Fishries. 2007. <http://www.maff.gov.kh/eng/statistics/crop>
- Ministry of Agriculture. 1993. Area and production of principal crops in India 1990-93. Directorate of Economics and Statistics (Department of Agriculture & Co-operation). Ministry of Agriculture, India.
- Muehlbauer, F. J.; Kaiser, W. J.; Clement, S. L. and Summerfield, R. J. 1995. Production and breeding of lentil. *Adv. Agron.* **54**: 283-332.
- Mung bean. [http://en.wikipedia.org/wiki/Mung\\_bean](http://en.wikipedia.org/wiki/Mung_bean)
- Murtaza, G.; Amin, Z.M.M.; Adil Choudhry, M.; Tanveer, A. and Ayub, M. 1999. Growth and yield response of mungbean (*Vigna radiata* L.) cultivars to varying levels of nitrogen. *Pakistan J. Biol. Sci.* **2**: 1378-80.
- Murti, V. S., Seshadri, T. R. and Subramanian, V. 1964. Neurotoxic compounds of seeds of *Lathyrus sativus*. *Phytochem.* **3**: 73.
- Nagrajan, V. and Gopalan, C. 1968. Variation in the neurotoxin ( $\beta$ -(N)-oxalylamino alanine) content in the *Lathyrus sativus* samples from Madhya Pradesh. *Indian J. Medical Res.* **56**:95.
- Namdeo, S. L.; Gupta, S. C. and Joshi, R. K. 1996, Influence of rhizobium inoculation on nodulation and yield of lentil genotypes under rainfed condition. *Lens News Letter* **23**: 24-26.
- Nath, V. 1972. Physiological investigations on growth and development in two varieties of field peas (*Pisum sativum* L.). Ph. D. Thesis, Agra University, Agra, India.
- Negi, S. C. and Shekhar, J. 1993. Response of french bean (*Phaseolus vulgaris*) to nitrogen. *Indian J. Agron.* **38**: 321-22.
- Ochatt, S. J. ; Muneaux, E. ; Machado, C. ; Jacas, L. and Pantécaille. 2002. The hyperhydricity of *in vitro* regeneration of grass pea (*Lathyrus sativus* L.) is linked with an abnormal DNA content. *J. Plant Physiol.* **159**: 1021-28.
- Odoardi, M.; Palmieri, S.; Giacomozzi, G. and Soressi, G. P. 1976. Enzymes of carbohydrate metabolism during seed ripening in smooth and wrinkled seeds. *Rivista di Agronomia.* **10**: 233-39.
- Oghoghorie, C. G. O. 1971. Physiology of field pea-*Rhizobium* symbiosis in the presence and absence of nitrate. Ph. D. Thesis, Univ. Belfast.
- Oghoghorie, C. G. O. and Pate, J. S. 1971. The nitrate stress syndrome of the nodulated field pea (*Pisum arvensis* L.) Technique for measurement and

evaluation in physiological terms. In: *Biological Nitrogen Fixation in Natural and Agricultural Habitats. Plant Soil* (special volume), pp. 185-202.

Oghoghorie, C. G. O. and Pate, J. S. 1972. Exploration of the nitrogen transport system nodulated legume using  $^{15}\text{N}$ . *Planta*. **104**: 35-49.

Oplinger E. S.; Hardman L. L.; Kaminski A. R.; Combs S.M. and Doll J. D. 1990. Mungbean. *Alternative Field Crops Manual*. Minnesota Extension Service, University of Wisconsin-Extension, University of Minnesota Center for Alternative Plant and Animal Products; May. 1-4.

Padmajaprasad, V.; Kaladhar, M. and Bhat, R. V. 1997. Thermal isomerisation of  $\beta$ -N-oxaly1-L- $\alpha$ ,  $\beta$ -diaminopropionic acid, the neurotoxin in *Lathyrus sativus* during cooking. *Phytochem*. **59**: 77-80.

Pandey, R. K. and Singh, V. B. 1981. Influence of partial defoliation on dry-matter production and seed yield of urd bean (*Vigna mungo* L. Hepper). *J. Agric. Sci.* **97**: 437-43.

Panwar, J. D. S. and Thakur, A K. 1994. Physiological and biochemical studies in VAM, *Rhizobium* inoculated mungbean plants under field condition in mycorrhizae, biofertilizers for future. III National Conference on Mycorrhiza, held at TERI, New Delhi, pp. 471-77.

Panwar, J. D. S. and Thakur, A. K. 1995. VAM Fungi: A potential supplier of phosphorus and micronutrients. *Farmers and Parliament*: May, pp. 23-24.

Panwar, J. D. S.; Abbas, S.; Sita Ram and Sirohi, G. S. 1988. Effect of BAP, ethrel and stem girdling on growth and partitioning of photosynthates in Y-shaped mung bean. *Indian J. Plant Physiol.* **31**: 418-22.

Pate, J. S. 1975. Pea. In: *Crop Physiology*. Evans L. T., (Ed.). Cambridge University Press, Cambridge, pp. 191-224.

Pate, J. S. and Flinn, A. M. 1973. Carbon and nitrogen transfer from vegetative organs to ripening organs of field peas (*Pisum sativum*). *J. Exp. Bot.* **24**: 1090-99.

Pate, J. S. and Flinn, A. M. 1977. Fruit and seed development. In: *The Physiology of Garden Pea*. Shutcliffe J. F. and Pate J. S., (Eds). Academic Press, New York, pp. 431-65.

Patra D. K. and Bhattacharya, P. 1997. Influence of root uodule bacterium on nitrogen fixation and yield of mungbean. *J. Mycopathol. Res.* **35**:47-49.

Pawar, S. E. and Bhatia, C. R. 1980. The basis of grain yield differences in mungbean cultivars and identification of yield limiting factors. *Theor. Appl. Genet.* **57**: 171-75.

Prasad, S. and Srivastava, J. P. 1999. Physiological analysis of yielding ability in mungbean. *Indian J. Pulses Res.* **12**: 49-56.

Price, D. N. and Hardley, C. L. 1980. Developmental and varietal comparison of pod carboxylase levels in (*Pisum sativum*). *Ann. Bot.* **45**: 283-94.



Queensland Government. Primary Industries and Fisheries, Australia. Lentils. <http://www2.dpi.gov.au/fieldcrops/9274.html>

Railton, I. D.; Reid, D. M.; Gaskin, P. and MacMillan, J. 1974. Characterization of abscisic acid in chloroplasts of *Pisum sativum* L. Var. Alaska by combined gas chromatography mass spectrometry. *Planta*. **117**: 179-82.

Rana, S. S.; Sood, P.; Singh, Y. and Rameshwar. 2003. Response of rajmash (*Phaseolus vulgaris* (L.) genotypes to potassium under dry temperate conditions of Himachal Pradesh. *Himachal J. Agric. Res.* **29**: 16-20.

Rao, S. L. N.; Adiga, P. R. and Sarma, P. S. 1964. The isolation of  $\beta$ -N-oxaly1-L- $\alpha$ ,  $\beta$ -diaminopropionic acid: A neurotoxin from the seeds of *Lathyrus sativus*. *Biochem.* **3**: 432-36.

Rathod, K. L. 1989. Status of *Lathyrus sativus* L. in India with special reference to Madhya Pradesh. In: *Grasspea: Threat and Promise. Proceeding of the International Network for the Improvement of Lathyrus sativus and the Eradication of Lathyrism*. Spencer P. S., (Ed.). Third World Medical Research Foundation, New York, pp 168-74.

Ravindran, V. and Blair, R. (1992). Feed resources for poultry production Asia and Pacific. II. Plant protein sources. *World Poult. Sci. J.* **48**: 205-31.

Ray, S. and Dalei, B. K. 1998. VAM for root knot nematode management and increased productivity of grain legumes in Orissa. *Indian J. Nematol.* **28**: 41-47.

Rebetzke, G. and Lawn, R. 2006. Adaptive responses of wild mungbean (*Vigna radiata* sp. Sublobata) to photo-thermal environment. II. Growth, biomass and seed yield. *Australian J. Agric. Res.* **57**: 929-37.

Roberts, E. H.; Summerfield, R. J.; Muehlbauer, F. J. and Short, R. W. 1986. Flowering in lentil (*Lens culinaris* Medic.): The duration of photoperiodic induction phase as a function of accumulated day length above the critical photoperiod. *Annals Bot.* **58**: 253-48.

Roper, Hans-Joachim; Graebe, J. E.; Gaskin, P. and Mac Millan, J. 1978. Gibberelline biosynthesis in a cell free system from immature seeds of *Pisum sativum*. *Biophys. Res. Commun.* **80**: 690-97.

Roy, D. N. and Rao, B. S. N. 1968. Distribution of  $\alpha$ -and  $\beta$ -isomers of N-oxaly1- $\alpha$ ,  $\beta$ -diaminopropionic acid in some Indian varieties of *L sativus*. *Current Sci.* **37**: 395-96.

Rudra, M. N. 1952. Toxic principle of *Lathyrus sativus*. *Nature*. **170**: 124-25.

Rybanski, W.; Szot, B. and Rusinek, R. 2008. Estimation of morphological traits and mechanical properties of grasspea seeds (*Lathyrus sativus* L.) originating from EU countries. *Int. Agrophysics.* **22**: 261-75.

Sadeghipour, O. 2008. Effect of withholding irrigation at different growth stages on yield and yield components in mungbean (*Vigna radiata* L. Wilczek)

varieties. *American-Eurasian J. Agric. Environ. Sci.* **4**: 590-94.

Sadeghipour, O. 2009. The influence of water stress on biomass and harvest index in three mungbean (*Vigna radiata* (L.) R. Wilczek) cultivars. *Asian J. Plant Sci.* **8**: 245-49.

Saini, J. P. and Negi, S. C. 1998. Effect of cultivar and date of sowing on growth and yield of french bean (*Phaseolus vulgaris*) under dry temperate conditions. *Indian J. Agron.* **43**: 110-13.

Sandhu, J. S. and Singh, S. 2007. History and origin. In: *Lentil: An Ancient Crop for Modern Time*. Yadav S. S., McNeil D. and Stevensen P. C., (Eds). Springer, pp. 1-9.

Sangakkara, U. R. 1996. Response of french bean (*Phaseolus vulgaris* L.) to rate and ratio of potassium fertilizer application. *Pertanika J. Trop. Agric. Sci.* **19**: 61-67.

Saran, B. 1995. Effect of light on nodulation and leghaemoglobin in blackgram. *New Agriculturist.* **6**: 127-28.

Saraswat, K. S. 1980. The ancient remains of the crop plants at Atranjikhha CC 2000-1500 BC. *J. Indian Bot. Soc.* **59**: 306-19.

Sarkar, S.; Singh, S. R. and Singh, Y. 2000. Effective use of harvested water in relation to productivity and water use pattern of rajmash as inter crop. *J. Indian Soc. Soil Sci.* **48**: 824-26.

Sarker, A.; Erskine, W.; Baker, M. A.; Rahman, M. M.; Yadav, N. K.; Ali, A. and Saxena, M. C. 2004. Role of lentil in human nutrition and crop diversification in Asia region. In: *Role of Legumes in Crop Diversification and Poverty Reduction in Asia*. Gowda C. L. L. and Pande S., (Eds). Proc. CLAN Steering Committee Meeting, 10-12 November 2003. ICRISAT, India, Patancheru, AP, India, pp. 234.

Sarker, B. C. and Karmoker, J. L. 2009. Effect of phosphorus deficiency on the root growth of lentil seedlings (*Lens culinaris* Medik.) grown in rhizobox. *Bangladesh J. Bot.* **38**: 215-218.

Savithri, K. S.; Ganapathy P. S. and. Sinha. S. K. 1978. Fruit and seed development in mung beans (*Phaseolus aureus* Roxb.). *Journal Agric. Sci.* **90**: 551-56.

Schatz, B. and Endres, G. 2003. NDSU. Field Pea Production. A-1166. <http://www.ag.ndsu.edu/pubs/plantsci/rowcrops/a1166w.htm>

Sekhon, H.S.; Bains, T.S.; Kooner, B.S. and Sharma, P. 2007. Grow summer mung for improving crop sustainability, farm income and malnutrition. In: *First International Conference on Indigenous Vegetables and Legumes. Prospects for Fighting Poverty, Hunger and Malnutrition*. Chadha M.I., Kuo G. and Gowda C.L.L., (Eds). *ISHS Acta Hort.* 752.

Shanmugasundaram, S.; Singh, G. and Sekhon, H. S. 2004. Role of mung bean in Asian farming systems and relevance of coordinated research and development



programs in Asia. *In: Role of Legumes in Crop Diversification and Poverty Reduction in Asia*; Gowda C.L.L., Pande S., (Eds). Patancheru, Andhra Pradesh: ICRISAT. pp. 194-203 ((AVRDC Staff Publication). [http://libnts.avrdc.org.tw/fulltext\\_pdf/eam0038.pdf](http://libnts.avrdc.org.tw/fulltext_pdf/eam0038.pdf)

Sharma, P.; Sekhon, H. S.; Khanna, V. and Singh, G. 2007. Biological nitrogen fixation in mungbean: Facts and findings. *In: First International Conference on Indigenous Vegetables and Legumes. Prospects for Fighting Poverty, Hunger and Malnutrition*. Chadha M. I., Kuo G. and Gowda C.L.L., (Eds). *ISHS Acta Hort.* 752.

Shrestha, R. 2005. Adaptation of Lentil (*Lens culinaris* Medikus subsp. *culinaris*) to rainfed environments-response to water deficit. Ph. D. Thesis, University of Western Australia, Crawley, WA, Australia.

Shrestha, R.; Siddique, K. H. M.; Turner, N. C.; Turner, D. W. and Berger, J. D. 2005. Growth and seed yield of lentil (*Lens culinaris* Medikus) genotypes of West Asian and South Asian origin and crossbreds between the two under rainfed conditions in Nepal. *Aust. J. Agric. Res.* **56**: 971-81.

Shrestha, R.; Turner, N. C.; Siddique, K. H. M. and Turner, D. W. 2006b. Physiological and seed yield responses to water deficit among lentil genotypes from diverse origins. *Australian J. Agric. Res.* **49**: 613-26.

Shrestha, R.; Turner, N. C.; Siddique, K. H. M.; Turner, D. W. and Speijers, J. 2006a. Water deficit during pod development in lentils reduces flower and pod numbers but not seed size. *Aust. J. Agric. Res.* **57**: 427-38.

Sindhu, S. S.; Gupta, S. K. and Dadarwal, K. R. 1999. Antagonistic effect of *Pseudomonas* spp. of pathogenic fungi and enhancement of green gram. *Biol. Fert. Soil.* **29**: 62-68.

Singh, T. 1977. Harvest index in lentil (*Lens culinaris* Medik.). *Euphytica*. **26**: 833:39.

Singh, Y. K. 1999. Growth, development and yield analysis of mungbean genotypes. M.Sc. Ag. Thesis, Department of Plant Physiology, Institute of Agric. Sci., Banaras Hindu University, Varanasi, India.

Smartt, J. 1990. Pulses of the classical world. *In: Grain Legumes: Evaluation and Genetic Resources*. Summerfield R. J. and Ellis E. H. (Eds). Cambridge Univ. Press, Cambridge, pp. 190-200.

Smith, D. L. 1973. Nucleic acid, protein and starch synthesis in developing cotyledons of *Pisum sativum* L. *Ann. Bot.* **37**: 795-804.

Snyder, F. W. and Carlson, 1984. Selecting for partitioning of photosynthetic products in crops. *Adv. Agron.* **37**: 47-72.

Souza, G. M.; Fernandes Viana, J. De Oliveira and Ferraz de Oliveira, R. 2005. Asymmetrical leaves induced by water deficit show asymmetric photosynthesis in common bean. *Brazilian J. Plant Physiol.* **17**: 223-27.

- Srivastava, J. P. 1981. Physiological analysis of yielding ability in field peas—photosynthesis and production of growth regulating substances. Ph. D. Thesis, IARI, New Delhi, India.
- Srivastava, J. P. and Bhardwaj, S. N. 1986. Contributions of different photosynthesizing organs to the pod in relation to 'source' and 'sink' interaction in field pea (*Pisum sativum* L. var. *arvensis* L.). *Indian J. Plant Physiol.* **29**: 262-66.
- Srivastava, J. P. and Bhardwaj, S. N. 1987. Accumulation capacity of seed, leaf photosynthetic rate and vascular translocation in regulating the seed size in pea. *Indian J. Agric. Sci.* **57**: 416- 18.
- Stephen, M. B.; Thomas, E. W.; Suzanne, N.; Matthew, E. B.; Steven, E.; Carol, H. C.; Betty, Y. S; John A. M. and Thomas, E. C. 2003. Evaluation of the estrogenic effects of legume extracts containing phytoestrogens, *J. Agric. Food Chem.* **51**: 2193–99.
- Summerfield, R. J. and Lawn, R. J. 1987. Tropical grain legume crops: A commentary. *Outlook Agric.* **16**: 189-97.
- Summerfield, R. J. and Lawn, R. J. 1988. Environmental modulation of flowering in mung bean (*Vigna radiata*): Further reappraisal for diverse genotypes and photothermal regimes. *Experimental Agriculture.* **24**:75-88.
- Summerfield, R. J.; Roberts, E. H.; Erskine, W and Ellis, R. H. 1985. Effect of temperature and photoperiod on flowering in lentils (*Lens culinaris* Medic.). *Annals Bot.* **56**: 659-71.
- Tawfik, K. M. 2008. Effect of water stress in addition to potassium application on mungbean. *Australian J. Basic Applied Sci.* **2**: 42-52.
- Takele-Haimanot, R.; Abegaz, B.M.; Wuhib, E.; Kassina, A.; Kidane, Y.; Kebede, N.; Alemu, T. and Spencer, P. S. 1993. Pattern of *Lathyrus sativus* (grass pea) consumption and  $\beta$ -N-oxaly1-L- $\alpha$ ,  $\beta$ -diaminopropionic acid ( $\beta$ -ODAP) content of food sample in the lathyrism endemic region of northwest Ethiopia. *Nutr. Res.* **13**: 1113-26.
- Thakur, A. K. and Panwar, J. D. S. 1995. Response of *Rhizobium*- vesicular arbuscular mycorrhizal symbionts on photosynthesis, nitrogen metabolism and sucrose translocation in green gram (*Phaseolus radiatus*). *Indian J. Agric. Sci.* **67**: 245-48.
- Thomas, R. M. J.; Fukai, S.; Peoples, M.B. 2004. The effect of timing and severity of water deficit on growth, development, yield accumulation and nitrogen fixation of mungbean. *Field Crops Research.* **86**: 67-80.
- Tomar, R. P. S. and Kumari, P. 1991. Hard seed studies in black gram (*Vigna mungo* L.). *Seed Sci. Tech.* **19**: 51-56.
- Tripathi, D. P.; Chandra, S. and Asthana, A. N. 1986. Technology for growing rajmash in plains. *Indian Farming* **36**: 13-15.



Tripathi, N. C. and Singh, N. P. 1989. Canopy characteristics, light interception and dry matter accumulation by lentil cultivars under varying row spacing and seedling rates. *Legume Research* **12**: 15-21.

USDA National Nutrient Database for Standard Reference, Release 23 (2010) ([http://www.nal.usda.gov/fnic/foodcomp/cgi-bin/list\\_nut\\_edit.pl](http://www.nal.usda.gov/fnic/foodcomp/cgi-bin/list_nut_edit.pl))]

van Kessel, C. 1994. Seasonal accumulation and partitioning of nitrogen by lentil. *Plant Soil*. 164: 69-76.

Van Staden, J. and Button, J. 1978. The cytokinin content of aseptically cultured pea fruits. *Z. Pflanzenphysiol.* **87**: 129-36.

Vavilov, N. I. 1951. The origin, variation, immunity and breeding of cultivated plants. Translated by K. Start. *Chronica Bot.* **13**: 1-366.

Vidal-Valverde, C. and Frias, J. 1992. Changes in carbohydrates during germination of lentils. *Zeitschrift fur Lebensmitteluntersuchung und Forschung A*. **194**: 461-64.

*Vigna mungo*. [http://en.wikipedia.org/wiki/Urad\\_%28bean%29](http://en.wikipedia.org/wiki/Urad_%28bean%29)

Vijaylakshmi, P.; Amirthaveni, S.; Devdas, R. P.; Winberger, K.; Tsou, S. C. S. and Shanmugasundaram, S. 2003. Enhanced bioavailability of iron from mungbean and its effect on health of school children. *AVRDC. Tech. Bull. No. 30*. Shanhua, Taiwan.

Waterer, J. G.; Vessey, J. K and Raper Jr, C. D. 1992. Stimulation of nodulation in field peas (*Pisum sativum*) by low concentrations of ammonium in hydroponic culture. *Physiol Plant.* **86**: 215-20.

Watt, E. E.; Poehlman, J. M. and Cumbie, B. G. 1977. Origin and composition of a texture layer on seeds of mungbean. *Crop Sci.* **17**: 121-25.

Weaver, R. W. and Miller, J. C. Jr. 1986. Remobilization of labelled nitrogen from vegetative tissues to pods of mungbean. *Plant Soil.* **94**: 1147-51.

Whitehead, S. J.; Summerfield, R. J.; Muehlbauer, F. J.; Coyne, C. J.; Ellis, R. H. and Wheeler, T. R. 2000. Crop improvement and the accumulation and partitioning of biomass and nitrogen in lentil. *Crop Sci.* **40**: 110-20.

Wikipedia. The Free Encyclopedia. Lentil. <http://en.wikipedia.org/wiki/Lentil>

Williams, R. W. 1989. 'A study of the causes of, and selection for resistance to weather damage in mungbean (*Vigna radiata* (L.) Wilczek; *V. mungo* (L.) Hepper)'. Ph. D. Dissertation, University of Queensland, Brisbane, Australia.

Winburger, K. 2003. Impact analysis of mungbean research in South and Southeast Asia. Final Report GTZ Project No. 99-9117-5. Shanhua, Taiwan: Asian Vegetable Research and Development Centre.

Xing, G. S.; Cui, K. R.; Wang, Y. F. and Li, Z. X. 2001, Water stress and accumulation of  $\beta$ -N-oxalyl-L- $\alpha$ ,  $\beta$ -diaminopropionic acid in grass pea (*Lathyrus sativus*). *J. Agric Food Chem.* **49**: 216-20.

- Yadav, V. K. and Mehta, S. L. 1995. *Lathyrus sativus* a future pulse crop free of neurotoxin. *Current Sci.* **68**: 288-92.
- Yan, Ze-Yi; Spencer, P. S.; Li, Zhi-Xiao; Liang, Yong-Min; Wang, Ya-Fu; Wang, Chun-Ying and Li, Fen-Min 2006. *Lathyrus sativus* (grass pea) and its neurotoxin ODAP. *Phytochem.* **67**: 107-21.
- Yang, H. M.; Zhang, X. Y. and Wang, G. X. 2004. Relationship between stomatal character, photosynthetic character and seed chemical composition in grass pea at different water availabilities. *J. Agric. Sci.* **142**: 675-81.
- Yeates, S.; Lawn, R. and Atkins, S. 2000. Prediction of weather damage of mungbean seed in tropical Australia. I Relation between seed quality, weather and reproductive development. *Australian J. Agric. Res.* **51**: 637-48.
- Zhang, Ji-Tao and Mu, Chun-Sheng. 2009. Effects of saline and alkaline stresses on the germination, growth, photosynthesis, ionic balance and anti-oxidant system in an alkali-tolerant leguminous forage *Lathyrus quinquenervius*. *Soil Sci. Plant Nutrition.* **55**: 685-97.
- Zhou, G. K.; Kong, Y. Z.; Cui, K. R.; Li, Z. X. and Wang, Y. F. 2001. Hydroxry radical scavenging activity of  $\beta$ -N-oxaly1-L- $\alpha$ ,  $\beta$ -diaminopropionic acid. *Phytochem.* **58**: 759-62.
- Ziska, L. H. and Blowsky, R. A. 2007. A quantitative and qualitative assessment of mungbean (*Vigna mungo* (L.)Wilczek) seed in response to elevated atmospheric carbon dioxide: Potential changes in fatty acid composition. *J. Agric. Food Chem.* **87**: 920-923.
- Zohary, D. and Hopf, M. 2000. *Domestication of Plants in the Old World*, 3<sup>rd</sup> edition. Oxford: University Press, pp. 105-07. ●



## **CHAPTER 11**

# **Arid Legume Crops and Their Adapatability**

### **COWPEA**

**C**owpea [*Vigna unguiculata* (L.) Walp.] belongs to family Fabaceae, subfamily Faboideae, tribe Phaseoleae, subtribe Phaseolinae, genus *Vigna* and section Catiang. There are four subspecies of it, viz. *V. cylindrical*, *V. dekindtiana*, *V. sesquipedalis*, and *V. unguiculata* (Wikipedia. The Free Encyclopedia, <http://en.wikipedia.org/wiki/Cowpea>). All cultivated species are grouped under *V. unguiculata* subspecies *unguiculata*. In India, it is called as *Chawali* or *Chavali* (Marathi), *Kāṛāmani* or *Kāṛāmani Payir* or *Thatta Payir* (Tamil) and *Lobia* (Hindi). It is also known *Ascrowder pea*, *Black-eyedpea* and *Southern pea*. Internationally it is known as *Lubia*, *Niebe*, *Coupe* or *Frijole*. In older references *Vigna unguiculata* has been referred to as *Vigna sinensis* (L.). It is cultivated mainly in tropical and subtropics of Africa, Asia, and South America (Thomas Jefferson Agricultural Institute. <http://www.jeffersoninstitute.org/pubs/cowpea.shtml>). It is also cultivated in southern Europe and the United States.

Cowpea originated in Africa. The history of cowpea dates to ancient West African sorghum and millet farming, i.e. 5-6 thousand years ago (Davis *et al.*, 1991). Largest area under cowpea production is in Central and West Africa. Annual global production is around 3.3 million tons.

It is primarily cultivated for seeds, but green pods and tender leaves are also consumed as vegetable. Cowpea seeds are highly nutritious for human being, as well as for livestock. Seeds contain about 24% protein and 60% carbohydrates. Fiber content in seeds is also high. Seeds are rich in mineral elements K, Ca, P, Mg and Se. Niacin, pantothenic acid and folate are also present in high amounts in seeds. Amino acids leucine, lysine, valine are also present in considerable amounts. Cowpea seeds contain trypsin inhibitors which limit protein utilization. Nutrient content of cowpea seed is summarized in Table 1.

Table 1. Composition of mature cowpea seed

Nutrient	Value per 100 g
Proximates	
Energy	1406.000 kJ
Protein	23.520 g
Total lipid (fat)	1.260 g
Ash	3.240 g
Carbohydrate, by difference	60.030 g
Fiber, total dietary	10.600 g
Sugars, total	6.900 g
Calcium	110.000 mg
Iron	8.270 mg
Magnesium	184.000 mg
Phosphorus	424.000 mg
Potassium	1112.000 mg
Sodium	16.000 mg
Zinc	3.370 mg
Copper	0.845 mg
Manganese	5.090 mg
Selenium	9.000 µg
Vitamins	
Vitamin C, total ascorbic acid	1.500 mg
Thiamin	0.853 mg
Riboflavin	0.226 mg
Niacin	2.075 mg
Pantothenic acid	1.496 mg
Vitamin B-6	0.357 mg
Folate, total	633.000 µg
Choline, total	94.700 mg
Vitamin B-12	0.000 µg
Carotene, beta	30.000 µg
Vitamin A, IU	50.000 IU
Vitamin E (alpha-tocopherol)	0.390 mg
Vitamin K (phylloquinone)	5.000 µg

Source: USDA National Nutrient Database for Standard Reference, Release 23 (2010). [http://www.nal.usda.gov/fnic/foodcomp/cgi-bin/list\\_nut\\_edit.pl](http://www.nal.usda.gov/fnic/foodcomp/cgi-bin/list_nut_edit.pl)



Cowpea is also grown as cover crop, green manure crop, and for fodder. It is reported that removing too many tender leaves from plant impairs grain yield, while removing oldest one improves it (Barrett *et al.*, 1997). Cowpea straw is excellent and valuable roughage for cattle. It is a shade tolerant crop, therefore, successfully intercropped with many cereals and root crops. Cowpea seeds contains about 25 per cent protein, especially rich in the amino acids, lysine and tryptophan, and is useful as a nutritional supplement to cereals.

Slightly acidic or slightly alkaline soils (pH 5.5-8.3) are best for the growth of cowpea. Crop is, to some extent, tolerant to salinity and high soil aluminium content, but not to waterlogging. Once crop is established, it is highly tolerant to drought (Valenzuela and Smith, 2002).

It is a warm season, erect, semi-erect or climbing annual crop with determinate to indeterminate growth. Growth habit varies from indeterminate to determinate. Non-vine type genotypes tend to be more determinate. Germination is epigeal, leaves are smooth, trifoliate and alternate. Leaf size and shape varies with variety and the agro ecological conditions. Plant has a strong tap root system, which goes deep in soil. Seed coat is smooth or wrinkled with various colours, viz. white, cream, green, buff, red brown or black. In some genotypes, referred to as 'eyed', white coloured hilum is surrounded by another colour (Daves *et al.*, 1991).

Seed germination, seedling emergence, appearance in sequence of flower buds, opening of flowers and pod maturation has base temperature between 8-11°C (Crauford *et al.*, 1997). Cowpea varieties are either day neutral or short day plant. However, Hadley *et al.* (1983) under controlled condition observed linear relationship between reciprocal of time taken to flower and both mean diurnal temperature and photoperiod. Therefore, concluded that flowering in cowpea is controlled by either mean temperature or photoperiod and the value of critical photoperiod is temperature-dependent. Flowers are born in multiple racemes on a long peduncle. Each peduncle bears four or more pods (Davis *et al.*, 1991). In short day accessions, exposure of only 2-4 short days are required for floral initiation, but it further need 20-short days for development to open flowers. Pod setting increases after exposure to even one short day more than the number required for flower opening (Lush and Evans, 1980). Floral buds at higher nodes require fewer short days for development to flowering than buds at lower nodes, and show faster rate of development. Inflorescence buds do not resume development if they are exposed to 15 or more long-days following inflorescence initiation. It is observed that any tendency towards synchronous flowering in cowpea is not due to the critical day-length for flower development being shorter than that for flower initiation, but due to the result of cumulative photoperiodic induction of plants and the more rapid development of later formed flowers (Lush and Evans, 1980).

In grain legumes yield is governed by the length of reproductive period, which in turn depends on the time from anthesis to maturity of individual pods, i.e. pod development period. In cowpea pod development period has been found to be positively correlated with seed weight. Long pod development period is reported to be correlated with rough seed coat texture (Wien and Ackah, 1978).

Cowpeas are grown under both irrigated and non-irrigated conditions. The crop responds positively to irrigation, but also produces well under dry land conditions. Cowpea is more drought resistant than common bean. Drought resistance is one reason that cowpea is such an important crop in many underdeveloped parts of the world. High rate of nitrogen and excessive moisture are detrimental for the crop as this may result in excessive vegetative growth, delayed maturity and pod shattering (Ali *et al.*, 2004). The most critical moisture requiring period of the crop is just prior to and during bloom (Davis *et al.*, 1991).

Once crop gets sufficient soil moisture to establish, it is a rugged survivor of drought and recovers from mid season dry spell. Tap root of plant can reach as deep as eight feet in soil within eight weeks. It can tolerate high temperature but can not tolerate frost (Khushik and Laghari, 2007). Water stress, during pod filling stage, results in reduction in leaf water potential, stomatal conductance, photosynthetic rate, and transpiration rate. During relief of water stress, recovery in photosynthesis rate lags behind the recovery in water relation parameters. During recovery period of water stress of pod filling stage there is an increase in leaf area, shift in dry matter partitioning in favour of leaf expansion, extended green leaf duration and increase in pod number (Bala Subramanian and Maheswari, 1992). It is reported that adaptation of cowpeas to semi-arid environments may be improved by selecting for early apportioning of carbohydrates to reproductive parts (Grantz and Hall, 1982).

Most sensitive growth stages to moisture stress in cowpea are flowering and pod filling. Reduction in seed yield ranges from 35-69% depending on the time and length of the drought (Shouse *et al.*, 1981). Seed yield of cowpea decreases by 50% due to water deficit occurring at flowering and pod filling stages (Shouse, 1979). Water stress on flower production, pod retention and the number of seeds per pod is reflected in reduction in seed yield per plant by 24, 56, 75 and 89%, respectively, under mild moderate, strong and severe stress (Jamadagni *et al.*, 2003; Peksen, 2007)

In soils low in phosphorus, the roots of cowpea develop effective mycorrhizal association increasing the availability of phosphorus (Valenzuela and Smith, 2002). Roots are infested by 'cowpea type' *Rhizobia* bacteria (a *Bradyrhizobium* species), which are present in almost all soils, but lacking or in very low in number in soils receiving rainfall less than 500 mm (Valenzuela and Smith, 2002). Cowpea nodulates



profusely, and unlike many other grain legumes, it provides a net gain in nitrogen in field even if seed is harvested (Khushik and Laghari, 2007). Normally cowpea crop contributes 40-80 kg N ha<sup>-1</sup>, while total amount of nitrogen fixation is 70-350 kg ha<sup>-1</sup> (Quin, 1997). The principal source of nitrogen in the development of cowpea changes with the developmental stage of the crop. During intense nitrogen fixation, average respiratory losses range 6.3-6.8 mg C mg<sup>-1</sup> N fixed. The amount of losses varies widely with the developmental stage (Ryle *et al.*, 1979). Soil supplies 80% of the total nitrogen assimilated in the above ground plant parts during first 42 days of growth, atmospheric nitrogen furnishes over 80% of nitrogen during remaining and most nitrogen demanding period of crop growth. At physiological maturity, the total above ground part of the plant has been reported to compose 100, 50 and 5 kg N ha<sup>-1</sup> as derived from atmosphere, soil, and fertilizers, respectively. It is also observed that pre-existing pools of N in vegetative parts do not contribute much nitrogen towards pod fill, and currently assimilated nitrogen, predominantly as derived by N<sub>2</sub>-fixation, contributes 87% of the nitrogen for the pod. Atmospheric nitrogen contributes significantly towards nitrogen nutrition of the crop and is an important source of nitrogen for pod development (Awonaike *et al.*, 1991). However, Douglas and Weaver (1989) observed that 50% of the nitrogen biologically fixed two days earlier moves to pods, and remaining is distributed in vegetative parts. They also concluded that much of the newly fixed nitrogen is cycled through the vegetative parts before reaching to the pods. Though high percentage of fixed-N or NO<sub>3</sub>-N during pod development phase moves to pods, other sinks, viz. leaves, nodules and roots etc., also compete for this newly acquired nitrogen (Douglas and Weaver, 1993).

It is estimated that nitrogen fixed after flowering contributes 40% of the fruit's total intake of nitrogen, mobilization of nitrogen fixed before flowering contributes the remaining 60%. Leaflets, nodulated roots, stem plus petioles and peduncle contribute mobilized nitrogen in approximate proportion of 5:2:1:1, respectively. Each fruit derives nitrogen from all current sources available, but nitrogen from leaves preferentially moves to the closest fruit (s), and lower fruits mobilize nitrogen from nodulated roots during late fruiting. Leaflets at upper fruiting nodes mobilize 70-77% of their nitrogen and concomitantly there is decline in net photosynthetic rate before senescing, where as leaflets at lower vegetative nodes (1-3) mostly fail to abscise, lose only 44-57% of their nitrogen and maintain photosynthetic rate actively throughout fruiting (Peoples *et al.*, 1983).

Flower drop is a major limiting factor in yield realization in cowpea. Substantial abortion of floral buds occurs when weather is uniformly hot during the vegetative and early reproductive stages, and sensitive genotypes produce virtually no flowers event though they initiate floral bud (Dow el-madina and Hall, 1986; Patel and Hall, 1990). High night temperature together with long photoperiods provided by combination of



halide and tungsten lamp is reported to result in complete suppression of floral bud development, while such effect was not observed when long photoperiod was provided by fluorescent and tungsten lamp. This indicated that in addition of the photoperiod, light quality also influences the effect of heat stress on floral bud development (Mutters *et al.*, 1989). It requires 2 weeks or more of consecutive or interrupted hot nights during the first 4 weeks after germination to cause complete suppression of the first five floral buds on the main stem (Ahmed and Hall, 1993). High night temperature at later stage of floral bud development has no effect on flower production, but results in male sterility, and hampers fruit set. (Warrag and Hall, 1984). Individual flower buds are sensitive to heat stress 7-9 days before anthesis, which coincides with the release of microspores from tetrads and is associated with heat-induced premature degeneration of the tapetal tissue that provides nutrients to developing pollen. Premature degeneration of tapetal layer and lack of endothelial development is supposed to be responsible for low pollen viability, low anther dehiscence and low pod set under high night temperature (Ahmed *et al.*, 1992). Under these conditions transfer of proline from tapetal layer to pollen is also inhibited (Mutters *et al.*, 1989). Differences are observed between heat sensitive and heat tolerant genotypes with respect to electrolytes leakage from leaf discs subjected to heat stress, and damage to pollen development under high night temperature is also probably follow the same way associated with heat-induced malfunctioning of membrane properties (Ismail and Hall, 1999). Inheritance of tolerance to heat-induced low pod set is under control of a single dominant nuclear gene (Marfo and Hall, 1992). Reduced yield under heat stress in cowpea is mainly due to reduction in pod set as well as in harvest index (Nelsen and Hall, 1985b; Ismail and Hall, 1998). Heat stress during reproductive growth stage may result in 13.5% reduction in first-flush grain yield per °C increase in daily minimum night temperature above 16.5°C (Ismail and Hall, 1998). Leaf membrane thermostability as determined by measuring electrolyte leakage from leaf discs under induced heat stress *in vitro* provides an efficient indirect screening technique for reproductive stage heat tolerance under field condition (Ismail and Hall, 1999).

Effect of variations in day/night temperatures viz., (mean value in parenthesis) 33/24°C (28.3°C), 33/19°C (25.6°C), 27/25°C (25.4°C), and 27/29°C (22.8°C) on pod development indicated that fruit produced in identical positions on main stem are almost identical in dry weight and morphology at the onset of flowering, but the overall mean dry weight of individual seed contained in the pod produced under coolest regime is more than double of that recorded in the warmest regime (Roberts *et al.*, 1978). High night temperature between midnight and dawn damaged pod set, whereas high night temperature between dusk and midnight has no such effect (Mutters and Hall, 1992).



Budget for the transfer of carbon from individual leaves and other source organs to fruit indicate that of the carbon translocated from leaves during fruiting 32% come from top most leaf, 28% from leaf below this, 16% from the next leaf, and the remaining 24% from lowest three leaves. Nearly 80% of fruits total intake of carbon comes from leaves and the rest from mobilization of stored carbon from other vegetative parts (Pate *et al.*, 1983). Analysis of xylem and phloem saps indicated that ureides and amides provide all of the fruit nitrogen requirements for net synthesis of amino compounds. The pod is initially the major site for processing and incorporating nitrogen, but later seed coats and then embryos become predominant. Ureides are broken down mainly in the pod and seed coat. Amide metabolism occurs in all fruit organs, but principally in the embryo during active seed growth. Seed coat releases nitrogen to embryo mainly as histidine, arginine, glutamine, and asparagine, hardly at all as ureide (Peoples *et al.*, 1985).

Under moisture stress of early flowering stage, reductions in biomass is due to reduction in leaf gas exchange and leaf area. Under moisture stress stomatal closure takes place, resulting in maintenance of leaf relative water content. Such drought avoidance by maintaining high leaf water content is negatively associated with leaf area as well as specific leaf area. Maintenance of CO<sub>2</sub> assimilation rate under water deficit is associated with high leaf relative water content. Decline in CO<sub>2</sub> assimilation rate is attributed mainly to stomata closure, however, some evidences of non-stomatal regulation are also observed. Significant genotypic variations in leaf gas exchange parameters are reported, which may be considered for identifying cowpea genotypes for agronomic fitness under drought. Water-use efficiency and instantaneous water-use efficiency (defined as a molar ratio of CO<sub>2</sub> assimilation to transpiration) are not directly associated, but instantaneous water-use efficiency and leaf internal CO<sub>2</sub> concentration (C<sub>i</sub>) are negatively related, while C<sub>i</sub> is moderately related with specific leaf area in this crop (Anyia and Herzol, 2004). Hall *et al.* (1990) using carbon isotopic discrimination technique observed that genotypic differences with respect to water-use efficiency can be readily detected using leaf samples. Water-use efficiency and carbon isotopic discrimination are strongly and negatively correlated in this crop, and these characters are controlled by nuclear gene in this crop (Ismail and Hall, 1993).

Bala Subramanian and Maheswari (1992) reported a decrease in LAR and SLA in stressed plants of a cowpea cultivar. The variability in leaf area, leaf area ratio and specific leaf area with respect to genotype and drought are interrelated but these parameters are not closely associated with biomass production or water-use, and no correlation between these parameters with water-use efficiency are found. These findings are in accordance with those of (Anyia and Herzol, 2004; Ismail and Hall, 1992).

Exogenously applied gibberellic acid is reported to increase vegetative growth, nodulation, yield components and seed yield in some cowpea genotypes, but such observation requires further validation with respect to optimal concentration of gibberellic acid, and time of application in different cowpea genotypes (Emongor, 2007).

As far as nutritional economy of the fruit of cowpea is concerned, it is observed that fruit fails to make net gain of  $\text{CO}_2$  from the atmosphere during the day time, although pod photosynthesis did play a role in fruit's carbon economy by re-fixation of a proportion of the fruit's respired  $\text{CO}_2$ . Of every 100 unit by weight of carbon entering the fruit, 70.4 are finally incorporated into seeds, 10.3 remains as immobilized material in pod walls, and the remaining 19.3 is lost in fruit respiration. Phloem supplies 97% of the fruits carbon and 72% of its nitrogen. The xylem contribution of nitrogen occurs mainly in early growth. Ninety six per cent of the fruit nitrogen is incorporated into seeds; approximately 10% of this is mobilized from the senescing pod (Peoples *et al.*, 1984). The mean transpiration ratio of fruit is very low, i.e. 8 ml water per g dry matter accumulated, which is because of the fruit's capacity to return up to 70% of its water intake back to the parent plant, probably via xylem (Peoples *et al.*, 1984).

Delayed leaf senescence, stem diameter, and leaf temperature are the potential traits as selection criteria for identifying drought tolerant genotypes of cowpea, and stem diameter may also be used as a single selection criterion without losing much accuracy (Chozin *et al.*, 2002). It is hypothesized that early partitioning of carbohydrate to reproductive parts results in improved drought resistance in this crop (Hall and Grantz, 1981).

## MOTH BEAN

Moth bean [*Vigna aconitifolia* (Jacq.) Marechal] is also known as mat bean, mout bean, matki bean, matak bean, drew gram, dew bean, Haricot papillion, Kallupayaru, Kheri, Kidney bean, Kumkumapesalu, Naripayaru, Pani payeru, Phillipesara, Tulkayari, Turkish gram, and Mittikele. The name moth bean is derived from *Hindi* name *moth*. It is an annual legume and belongs to family Fabaceae (Wikipedia, [http://en.wikipedia.org/wiki/Moth\\_bean](http://en.wikipedia.org/wiki/Moth_bean)). It is indigenous to the Indian subcontinent and originated in semi-arid regions of India, probably in Rajasthan (Bailey, 1953; Fageria, 1997). In India it is found from sea level to 1500 m elevations (FAO, <http://ecocrop.foa.org/ecocrop/srv/en/crop>).

It is grown in dry parts of South Asia. It is most popular grain legume crop in India and cultivated in the states of Rajasthan, Maharastra, Haryana, Punjab, Andhra Pradesh and Orissa. In India, its earlier mention is in Yajurveda (7000 BC), and Kautilya (321-296 BC) also has mentioned moth bean as a rainy season crop of India (Nene, 2006). In arid regions



of Rajasthan it a main source of dietary protein. Its green pods are consumed as a vegetable and the plant being highly palatable and rich in protein forms an excellent fodder (Srivastava and Soni, 1995). Moth bean has also been tried as a cattle feed in Texas and California. Though moth bean seeds are fed to oxen and horses, in cattle it prevents the flow of milk (Watt, 1889). The crop has been grown with satisfactory yield in south-eastern Queensland (Wikipedia, <http://en.wikipedia.org/wiki/Mothbean>). The nutritive value of mature moth bean seeds is given below in Table 2. Principal fatty acids in 100 g seeds are linoleic acid 485 mg; palmitic acid 313 mg; linoleic acid 265 mg; oleic acid 129 mg and stearic acid 51 mg (USDA, 2005).

**Table 2.** Nutritive value of moth bean seeds (expressed as per 100 g edible portion

Component	Value (per 100 g edible portion of seeds)
Water	9.70 g
Energy	1435.00 kJ (343 kcal)
Protein	22.90 g
Fat	1.60 g
Carbohydrate	61.50 g
Ca	150.00 mg
Mg	381.00 mg
P	489.00 mg
Fe	10.90 mg
Zn	4.80 mg
Vitamin A	32.00 IU
Thiamine	0.56 mg
Riboflavin	0.09 mg
Niacin	2.80 mg
Vitamin B6	0.37 mg
Folate	649.00 µg
Ascorbic acid	4.00 mg
Tryptophan	147.00 mg
Lysine	1248.00 mg
Methionine	220.00 mg
Phenylalanine	1028.00
Valine	734.00 mg
Leucine	1541.00 mg
Isoleucine	1138.00 mg

Source: USDA, 2005; Cited by Brink and Jansen, 2005

It is a small hanging plant with branches, and attains a height of about 30 cm. Plants are semi spreading, semi-erect and erect-upright. On account of its spreading habit of growth, it acts as living mulch, shielding the soil from the sun's heat preventing cracking and crust formation, reducing soil moisture and organic matter losses and reducing soil erosion in sandy areas (Soni, 1992; Srivastava and Soni, 1995; Wikipedia, <http://en.wikipedia.org/wiki/Mothbean>). In India it is grown in rotation with pearl millet each year or as a mixed crop with guar, pearl millet and mungbean.

Moth bean is a short duration crop. Sowing is done in July/August. Optimal temperature for growth and development is 25-30°C. Maturity period of crop varies from 55-90 days. In India the average seed yield is 300-400 kg ha<sup>-1</sup>, and in United States 1240 to 1800 kg ha<sup>-1</sup>. Yield of green matter for forage is 40-60 tonnes ha<sup>-1</sup> and of hay 7.5-12.0 tonnes ha<sup>-1</sup> (FAO. <http://ecocrop.fao.org/ecocrop/srv/en/crop>). Moth bean is highly adapted to rainfed arid conditions, highly tolerant to drought and high temperature. It can be grown successfully in soils with sandy or sandy-loam texture and well drainage with a wide range of soil pH (4-8), therefore, it is a popular crop in Thar Desert of Rajasthan, where rainfall is low and soil is alkaline. Some varieties grew with a rainfall of 50-60 mm in Thar Desert of Rajasthan. However, reasonable yield is obtained if this rain is distributed equally during crop growth period of 60-70 days (Fageria, 1992). On an average, the evaporation rate of the crop is 1.8-2.2 mm day<sup>-1</sup> during emergence and early growth stages, with a maximum of 4.8 mm day<sup>-1</sup> during flowering and pod forming stages (Singh *et al.*, 2000). Existing varieties of 72-75, 65-76, 60-62 and 57-58 days maturity periods, respectively, with semi-spreading, semi-erect, erect-upright plant types are suited to 450-500, 300-450, 150-300 and 130-150 mm rainfall, respectively, with reasonable grain yield potential of 500-1400 kg ha<sup>-1</sup> (ICAR News Success Story. <http://www.icar.org.in/node/680>).

Being a leguminous crop, it has capability to improve soil fertility. Roots are infested with *Rhizobium*, which fixes atmospheric nitrogen. No work has been done on nutritional requirements of the crop, but it is reported that for better yield crop requires 12.5 kg N, 25 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> and K<sub>2</sub>O as per soil K level after soil testing (Zonal Agricultural Research Station, Shilapur. Dryland Technology. Integrated Nutrient Management). Varietal variations in rate of influx of N, P and K in plants are observed, and have been associated with the yielding potential of the varieties, as varieties with high rate of influx of these elements are found to yield higher (Tarafdar and Kumar, 2003). *Rhizobium* inoculation to moth bean varieties improves nodulation in terms of number and dry weight of nodules per plant and enhances seed and fodder yield significantly. When compared with uninoculated control, the mean number and dry weight of nodules plant<sup>-1</sup> is reported to increase by 39.5 and 36.6 per cent and seed and fodder yield by 10.8 and 19.0%, respectively (Rathore and Chhipa, 1996).



Early varieties produce lesser amount of total dry matter and seed yield than the late varieties. In late varieties the maximum amount of dry matter accumulation occurs between 60-75 days after sowing and in early varieties between 45-60 days after sowing. The maximum leaf area per plant as well as leaf area index increase significantly between 30-40 days after sowing in early genotypes and between 45-60 days after sowing in late genotypes (Soni, 1992). Excessive leaf area development during reproductive growth phase may lead to reduction in photosynthetic efficiency of the crop due to shading of leaves present in the lower strata of the crop canopy (Srivastava and Soni, 1995). The maximum dry matter accumulation by plants coincides with the period of active growth of the pods. Relative growth rate and net assimilation rate are the maximum between 30-45 days after sowing; there after declines (Soni, 1992). Transpiration rate of crop increases steadily from vegetative to reproductive stage (from  $38 \mu\text{g H}_2\text{O cm}^2 \text{ sec}^{-1}$  to  $110 \mu\text{g H}_2\text{O cm}^2 \text{ sec}^{-1}$ ) (Srivastava and Soni, 1995).

Moth bean is a short-day and self pollinated crop. Flowers are very small, yellow in colour and born in clusters on 5-10 cm long axillary hairy branches. Days to 50% flowering varies in genotypes according to their maturity period ( $\sim 33$  days after sowing, in early varieties and 57 days after sowing, respectively). In moth bean time required to flower and maturity are considered to be the main determinant of seed yield (Mishra, 1976). Like other legumes, pod growth in moth bean is biphasic. First there is an increase in the length and width of the pod, then in the dry weight. The maximum rate of pod and seed dry weight accumulation occurs between 10-15 days after anthesis, which levels off at about 20 days after anthesis (Soni, 1992). No reduction in the weight of fruit walls is reported at the time of maturity, indicating that in moth bean remobilization of fruit walls accumulated assimilates takes place during pod maturity (Soni, 1992). Pods are 2-4 cm long bearing 4-6 seeds per pod. Seeds contain 22-24% protein; it contains trypsin inhibitor, which makes it unavailable (Information on Moth bean. <http://www.agricultureinformation.com>). The harvest index of crop is poor (23%- 36%) and test weight (1000 seed weight) ranges between 25-32 g (Srivastava and Soni, 1995).

Moth bean is known for its drought and heat resistance characters; therefore, it is the most adaptive legume to rainfed arid region (Kharb *et al.*, 1987). Crop adopts avoidance strategy to resist drought (Srivastava and Soni, 1995). Under rainfed condition genotypic differences in leaf water potential was not observed, but significant differences are reported in leaf osmotic potential. Osmotic potential reaches to its lowest value at about 45 days after sowing, which coincides with the maximum NAR in crop (Srivastava and Soni, 1995). Crop responds to rainfall. In Bikaner district of Rajasthan, which falls in arid region and represents around 25% moth bean cropped area of the state, productivity was  $139.1 \text{ kg ha}^{-1}$  in the years when the rainfall during July-September was 191 mm, but



increased to 613 kg ha<sup>-1</sup> in the years when the rainfall was around 400 mm during the same period. The relationship between crop yield (Y) and rainfall during July- September is reported to be linear ( $Y = 0.81X - 14.8$ ;  $r = 0.6245$ ). However, the crop yield is very sensitive to soil moisture stress at pod filling stage as the crop yield is reported to be associated better with the rainfall during pod filling stage ( $Y = 3.05X + 78.3$ ;  $r = 0.8116$  (Narain *et al.*, 2001).

Productivity of the crop is poor. In India, moth bean is a neglected crop. It is primarily grown under rainfed condition, which causes poor seedling emergence and seedling mortality resulting in patchy and poor plant stand (Narain *et al.*, 2001). Like other legumes, its harvest index is poor. It is also highly susceptible to yellow mosaic virus disease. Not much work has been done regarding its fertilizer requirements, phenology and ideotype for specific agro-climatic region. The crop has immense potential in arid and semi-arid regions and there is an urgent need to undertake moth bean improvement programme.

## GUAR

Guar [*Cyamopsis tetragonolobus* (L.) Taub.], also known as guar bean, cluster bean, gavar, gawar, goor, gowaree, gouree, govar, guara, gunwar, guwara, kothaverai, capparadavari, cottaveraykai, gawarkai, guaerdou, gorani, gori, guaru, gruar, gorakshaphalini, goreekaye, guvarpalli, goor-chikurkai, gorechikudi, guanra chhuim jhar sim, babachi, kotha-marakka, kotthavarai, kothavara, kotaranga, kottavarai, pe-walee, mgwaru, kotaranga, walee-pe, mgwarubavachi, bakuchi, gorakshaphalini, kayi, khurti, kulti, kuwara, siam bean, vah, vahkiphali, kotaranga, or cyamopse a quatre ailes belongs to family Fabaceae, subfamily Faboideae and tribe Indigofereae. It is a bushy annual shrub originated in India (FAO. <http://ecocrop.fao.org>).

World wide annual guar production is between 7.5 to 10.0 lakh tons and India is the major producer, sharing about 80% of the global production. Other guar producing countries are Pakistan, Sudan, USA, South Africa, Brazil, Malawi, Zaire and Australia. It was introduced into the United States in early 1903 from India. In India major producing states are Rajasthan, Gujarat, Haryana, Punjab, Uttar Pradesh, Madhya Pradesh, Tamil Nadu, Maharashtra, Karnataka and Andhra Pradesh. Rajasthan is the largest producer of guar, producing nearly 70% (around 4.2 lakh tons) of total production in the country. Haryana and Gujarat are at second and third places, respectively. In Rajasthan, Churu, Bikaner, Jaisalmer, Barmer, Nagaur, Hanuman Garh, Jodhpur, Ganganagar, Jaipur, Sirohi, Dausa, Jhunjhunu and Sikar. In Haryana it is grown in Bhiwani, Gurgaon, Mahendragarh and Rewari districts, while in Gujarat Kuch, Banaskantha, Mehsana, Sabarkantha, Vadodara and Ahmedabad districts (CRN. India. <http://www.crnindia.com/commodity/guar.html>).



Green plants are fed to cattle or used as green manure by digging up to any time before flowering. It is also grown as a cover crop to suppress weeds. Immature pods of guar are used as vegetable. Seeds are mainly used for extraction of gum, commercially known as ‘guar gum’. Guar seed has three parts i. e., germ (40-46%), endosperm (38-45%) and husk (14-16%) (Guar Gum. [http://www.guargum.biz/guargum\\_faqs.html](http://www.guargum.biz/guargum_faqs.html)). The nutritional composition of guar seeds is given in Table 3.

**Table 3.** The nutritional composition of guar seeds

Parameter	Per 100 g edible portion
Energy (k cal)	48.00
Moisture (g)	85.50
Protein (g)	3.50
Fat (g)	0.20
Carbohydrate (g)	8.10
Vitamine A (IU)	1861.00
Thiamine (mg)	0.07
Riboflavin (mg)	0.09
Niacin (mg)	0.90
Ascorbic acid (mg)	14.00
Calcium (mg)	72.00
Phosphorus (mg)	59.00
Iron (mg)	2.50

Source: Salunkhe and Kadam, 1998

Guar gum is extracted from endosperm. Guar gum is chemically galactomannan (19-43% of whole seed) consisting of a (1-4)-linked  $\beta$ -D-mannopyranose backbone with branch point from their 6-position linked to  $\alpha$ -D-galactose. There are, on an average, 1.5-2 mannose residues for every galactose residue. After extraction of gum, guar meal contains about 35% protein, which is about 95% digestible (Undersander *et al.*, <http://www.hort.purdue.edu/newcrop/AFCM/guar.html>).

Guar gum is edible, soluble in hot and cold water, but insoluble in organic solvents and has unique characteristics, viz. grease resistance, high viscosity, and capacity to function at low temperature. It is used as natural thickener, emulsifier, stabilizer, bonding agent, hydrocolloid, gelling agent, soil stabilizer, natural fiber, flocculent and fracturing agent, and mainly used in food industries. Guar gum is also used in textile industry, oil and gas drilling, mining, construction, pharmaceuticals, cosmetic industries and many other industries (Guar Gum. [http://www.guargum.biz/guargum\\_faqs.html](http://www.guargum.biz/guargum_faqs.html)). Being non-ionic guar gum is not affected by ionic

strength or pH, but degrades at extreme pH and temperature (e. g., at pH 3 and temperature 50 °C).

Guar is sown after first shower in July/August and harvested in late-October/early-November. Crop is planted when soil temperature is above 21°C. The optimum soil temperature for germination is 30°C. During germination hydrolysis of galactomannans, stored in seeds, is catalyzed by three enzymes, viz.  $\alpha$ -D-galactosidase,  $\beta$ -D-mannanase and  $\beta$ -D-mannosidase. A warm seedbed, adequate soil moisture, full sunshine and warm growing weather are essential for the establishment of the stand. Optimum temperature for root development is 25-35°C. The plant may attain a height of 1-2 m. Leaves are alternate and trifoliate. Leaflets are ovate; 5-10 cm long, distantly serrated and terminal leaflet is largest in size.

Determinate varieties mature in 60-90 days, while indeterminate varieties require 120-150 days to mature. High rainfall induces more vegetative growth and reduces pods per plant as well as seeds per pod. Waterlogging adversely affects plant growth and productivity. It requires 20- 40 cm rainfall in 3-4 spells. Crop is sown when soil moisture is adequate for germination, there after it requires one rainfall at the time when crop buds (mid vegetative) and one rainfall when crop comes up well and blossoming starts (Quadir and Ahmad, 2009). It grows best in sandy soils and considered to be tolerant to both salinity and alkalinity. It tolerates a wide rang of pH (5.3-8.3), but moderately alkaline pH (7.0-8.0) is considered to be desirable for the production of the crop. Branching type of varieties are more suitable for seed production, while erect single stemmed varieties are more suitable for pod production. Plants are generally sown in rows with plant to plant distance of 20-30 cm in a row, and row to row distance of 45-65 cm (Salunkhe and Kadam, 1998). In Rajasthan, yielding potential of the crop is limited by erratic rainfall and poor soil fertility (Garg and Burman, 2002). Though the crop does not require much fertilizer, but for higher pod production additional doses of fertilizers are required. A basal dose of 12-24 kg nitrogen and 60-74 kg each of phosphorus and potash and 12-24 cartload of FYM per ha is required (Salunkhe and Kadam, 1998).

Being a leguminous plant, guar is capable to fix atmospheric nitrogen. *Rhizobium* infesting guar roots belongs to cowpea group 'E'. earlier it was reported that in nodules of guar ureides are synthesized and export. (Pate *et al.*, 1980), but Sheoran *et al.* (1982) observed that amides are the major form of nitrogen which are being translocated.

It is a short-day plant. Some of the genotypes are day-neutral. Racemes are present on main stem and lateral branches. Raceme may attain a length of 10 cm. Flowers are typically papilionaceous and self-pollinated. Only 25-50 m isolation distance is required for the production of foundation and certified seeds. Pods are oblong and 5-12 cm long having 5-12 seeds per pod. Seeds are oval or cube-shaped having variable



size and colour (white, gray or black). Green pods are formed after 45-55 days of sowing and are generally harvested after 50-90 days after sowing. Green pods ripe after 90-160 days after sowing.

While working on two guar genotypes of contrasting branching pattern and planting densities at two sowing dates, Beech and Charles-Edwards (1984) reported no differences in the light utilization efficiencies between the genotypes or between the treatments. Gross partitioning of new dry matter between leaves, stem and roots also did not vary. Significant varietal differences are observed in mean dry weight of stem associated with each internodes, mean leaf weight and specific leaf area (Beech and Charles-Edwards, 1984). It is estimated that percentage of shoot dry weight in reproductive parts (pod) at 150 days after planting (DAP) varies from 41-79% depending upon genotype, while percentage stem weight, expressed as a percentage of shoot dry weight accounts for 36% at 60 DAP and 40 % at 150 DAP. Percentage in leaves decreases from 60% at 60 DAP to 0% at 150 DAP (Stafford, 2008). The number of growing vegetative meristems (branches and main stem) per unit ground area at the start of reproductive growth are reported to be linearly related to the amount of the incident light energy intercepted, and it is hypothesized that each vegetative meristem requires a minimum amount of assimilate flux to continue growth. It is also reported that meristems on the highly branching type varieties require approximately one-quarter of the assimilate flux required by the vegetative meristem on the relatively non-branching varieties (Charles-Edwards and Beech, 1984).

Harvest index of crop is poor and varies from 20% to 40% depending upon the genotype, however, this parameter is reported to be unaffected by water-optimal or water-stressed condition (Stafford, 2008).

Guar is a drought hardy plant and, therefore, successfully grown under arid and semi-arid conditions with frequent rainfall. Under drought plants do not die but the growth is suspended and maturity is delayed. Intermittent growth enables the plants to withstand drought (Undersander *et al.* <http://www.hort.purdue.edu/newcrop/AFCM/guar.html>). Genotypes of medium maturing duration generally exhibit relatively higher water-use efficiency (16.3-19.2) than the early and late maturing genotypes (Stafford, 2008). The component of yield most affected by water stress is number of pods plant<sup>-1</sup>. Seed weight, seeds pod<sup>-1</sup>, and racemes plant<sup>-1</sup> each had positive, but progressively smaller effects on seed yield (Stafford and NcMichael, 2008). Specific leaf area of the crop has been reported to be significantly correlated with seed yield and leaf relative water content, and suggested as a potential selection criterion for improving yield of the crop under rainfed condition (Talwar *et al.*, 2008).



### WINGED BEAN

Winged bean (*Psophocarpus tetragonolobus*), also known as Goa bean, Asparagus pea, Winged pea, Princes bean, Sirahu avarai (Tamil), Dambala (Sinhala) and Kacang botol (Malaysia), Kicipir (Indonesia), Jaat (Sundanese), Sigarillas (Togalog), Tua phoo (Thai), dragan beam (Vietnamese), is a member of family Fabaceae (Winged bean. [http://www.absoluteastronomy.com/tropics/Winged\\_bean](http://www.absoluteastronomy.com/tropics/Winged_bean)). It is a tropical legume. Its origin is disputed, and at least four possible sites viz., Papua New Guinea, Mauritius, Madagascar (the Malagasy Republic) and India, have been suggested. The centers of greatest diversity are Papua New Guinea and Indonesia; however, increasing numbers of varieties have recently been discovered in Thailand and Bangladesh (Weil and Belmont, 1991). Winged bean is a potentially important and exceptionally productive crop in the humid tropics (Lynd *et al.*, 1983). It grows well in humid tropics with high rainfall, and is an important vegetable crop through out southeastern Asia and Papua New Guinea. Winged bean is grown in Philippines, Indonesia, Vietnam, Cambodia, Papua New Guinea, Myanmar, Thailand, India, Bangladesh and Sri Lanka in wet as well as in dry zones up to an elevation of 1000 m (Weil and Belmont, 1991). Some varieties are also grown in United States, Western Australia and Queensland. In India it was introduced in 1799, and is grown in Assam, Tripura, Meghalaya, West Bengal, Orissa and other southern states (The Hindu, 2002. <http://www.hinduonnet.com/set/2002/09/26>). In Papua New Guinea, Myanmar and Thailand winged bean is grown as a field crop, while in other countries it is planted along the rice field borders, hedges, and roadside fences or in home gardens (Weil and Belmont, 1991). Winged beans are also grown as cover crop to protect the soil beneath the plantation crops. Genotypes with small leaf size are grown along with plantations in Sri Lanka and Malaysia.

Winged bean is an indeterminate perennial, climber with several branches and grown annually (Eagleton *et al.*, 1985). Plants may attain a height of 5 m. It requires some kind of support to attain high yield (Thompson and Haryono, 1980). Almost every part of the plant is tasty and edible (The Hindu, 2002. <http://www.hinduonnet.com/set/2002/09/26>). The fresh young pods are similar to green beans and have chewy texture and a sweet taste. Cooked leaves are like spinach and flowers taste like mushroom. The fleshy roots are having nutty flavour (Asian Vegetable Seeds – EvergreenSeeds. <http://www.evergreenseeds.com/wingedbean.html>). Winged bean pods are rich source of proteins, carbohydrates and vitamin A (300 to 900 IU) when consumed as salad and vegetable. Top tender leaves contain 5.0 to 7.6% protein, 3.0 to 8.5% carbohydrate and vitamin A (20.000 IU), which are also eaten raw or cooked. Seeds contain 29.8 to 39.0% protein, 15.0 to 18.0% oil and 23.9 to 42.0% carbohydrate. Nutritionally oil is of lower quality than the soybean oil. Fatty acid composition of oil is similar to groundnut oil in



the properties, and contains higher amounts of long chain saturated fatty acids, but it also contains 60% unsaturated fatty acids. Oil contains behenic acid, but it has no ill effects in infants. Oil contains acceptable amount of unsaturated fatty acids, especially linoleic acid, but as compared to soybean the amount is less in winged bean. High amount of tocopherols (Vitamin E) is present in seeds; which is an anti-oxidant and improves the utilization of vitamin A in human. Levels of raffinose and stachyose, which causes flatulence in human, are also low in winged bean seeds than in soybean seeds (N.A.S., 1981). In Papua New Guinea, it produces tuber (Khan, 1976), which contains 12.2 to 15.0% protein, 0.5 to 1.1% fat and 27.2 to 30.5% carbohydrate, are also consumed. Tubers contain some amount of anti nutritional factor viz., trypsin inhibitor and peel contains some tannin (N.A.S., 1981). Nutritive value of winged bean seeds is comparable to soybean seeds. Because of these features, winged bean has received world-wide attention (N.A.S., 1975; Yanagy, 1983).

Nutritive value of winged bean seeds is comparable to soybean seeds. Because of these features, winged bean has received world-wide attention (N.A.S., 1975; Yanagy, 1983). In spite of multiple uses and high nutritive value, it is grown mostly in home gardens and is listed as a neglected tropical bean.

Seed germination in winged bean is poor (50 to 60%). It is due to their hard coat, which reduces diffusion of water in seed resulting in decreased and delayed seed germination. When seeds are put in water, some seeds imbibe while others do not. Only those seeds which imbibe, germinate in moist soil without any treatment, while others do not. Mechanical scarification of seeds increases seed germinability up to 90% (Asian Vegetable Seeds – EvergreenSeeds. <http://www.evergreenseeds.com/wingedbean.html>). Over night soaking of seeds in water or dilute sulphuric acid make them to germinate more quickly and uniformly. Up to initial seven weeks plant growth is slow, thereafter it increases rapidly (Weil and Belmount, 1991). Leaves are tri foliate. Some tuber forming varieties of winged beans reproduce from tuber. Formation of tuber is vertical factor and influenced by environmental factors viz., temperature, day length/planting date and certain cultural practices (Kort and Cadwell, 1984). Tuber initiation is observed in plants under photoperiod below 20 h (Schiavinato and Vlio, 1996).

Winged bean grows well in well drained loamy soils. It can not tolerate very alkaline or very acidic soil pH and plant is susceptible to aluminum toxicity (Weil and Belmount, 1991). Ideal pH for growth is between 5.5 and 4.3. Plants respond to applied K and P. It is one of the best nitrogen fixer and its fertilizer requirement is low. It is reported to accumulate nitrogen @ 2.3 to 2.7 kg N ha<sup>-1</sup> day<sup>-1</sup>. Of the total shoot nitrogen, 34% is confined to seeds (Weil and Belmount, 1991). *Rhizobium* that nodulates in winged beans, belongs to cowpea group and most tropical soils contain rhizobia suitable for inoculation. Plants grown



on supports accumulate significantly higher amount of nitrogen in seeds. Nitrogenase activity increases with the onset of flowering, but decreases during pod formation stage (Motior *et al.*, 1998). Plants respond well to organic fertilizers and biofertilizers (The Hindu, 2002. <http://www.hinduonnet.com/set/2002/09/26>). Roots accumulate higher concentrations of Ca, K, P, Fe and Mn than aerial plant parts (Chow and Price, 1989). As a cover crop in banana plantations, it increases soil fertility and provides additional source of income when bananas are not producing (Weaver, 2007).

Though winged bean requires ample and well-distributed rainfall, but it can resist drought. It can also tolerate high temperature, but is very susceptible to frost (Weil and Belmont, 1991). Plants under 30/25°C day/night temperatures, produces higher shoot dry mass and leaf area, while highest tuberous root dry mass is produced under 25/20°C day/night temperatures (Schiavinato and Válio, 1996).

It is a short-day plant and flowers when day-length is just above 12 hours (The Hindu, 2002. <http://www.hinduonnet.com/set/2002/09/26>). Continuous day temperatures of more than 32°C or lower than 18°C, inhibit flowering even under suitable photoperiod (Weil and Belmont, 1991). Flower initiation is observed in plants under photoperiod below 20 h. Plants under inductive photoperiods only flower when grown at 25/20°C day/night temperatures (Schiavinato and Válio, 1996). Flowers are large and pale blue in colour. Though it is a self pollinated plant, cross pollination to the extent of 20% by bees is observed (Weil and Belmont, 1991). Pods grow up to 15 to 22 cm in length, flat and covered with frilly wings along four edges running lengthwise. Initially pod increases in length, which reaches to its ultimate size in about 20 days after pollination, which is followed by another about 44 days with the growth of the contained seeds (Weil and Belmont, 1991). Fresh weight of fruit walls increases till 30 days after flowering, which decreases gradually thereafter. Seeds grow actively after 30 days of flowering and reach maturity after about 65 days of flowering. The moisture content in seeds decreases steadily as the seeds mature, while lipid content increases gradually and reaches to the maximum level 6 weeks after flowering. In early stage of seed development (2 weeks after flowering) concentration of polar lipids (glycolipids and phospho lipids) is more than the neutral lipids, but as the seeds develop neutral lipids gradually accumulate while polar lipids decline until 6 weeks after flowering, there after their levels remain unchanged. As seeds mature, the levels of palmitic acid and stearic acid decreases but, the level of behenic acid is increased. Oleic acid content increases while, that of linolenic acid decreases rapidly as seeds mature. Concentration of linoleic acid fluctuates during development of seeds (Khor, 1985). Accumulation of acidic and basic lectins in seeds appear after 30 and 40 days of flowering, respectively (Higuchi, *et al.*, 1988). Mature pods contain 5 to 20 seeds per pod. Winged bean bears fruits over



a long period of time, and requires regular harvesting (Martin and Delpin, 1978). Removal of generative organs, particularly of floral buds, results in significant increase in dry matter in leaves and stems. Removal of 10-15 days old pods increases total number of pod production. Removal of both, floral buds and immature pods, increases total dry matter in tuber (Qazi and Caesar, 1989).

Vegetative growth and flower and pod production are more when plants are staked vertically (Schiavinato and Vlio, 1996). Harvest index is reported to be 17.5 to 20% and seed yield of around 2 tonnes ha<sup>-1</sup> in Papua New Guinea tuber yield of 11.7 tonnes ha<sup>-1</sup> has been recorded (Weil and Belmont, 1991).

Though the crop is of immense economic importance, not much work has been done to improve its productivity and to popularize it in farmers in India.

## REFERENCES

- Ahmed, F. E. and Hall, A. E. 1993. Heat injury during early floral bud development in cowpea. *Crop Sci.* **33**: 764-67.
- Ahmed, F. E.; Hall, A. E.; DeMasson, D. A. 1992. Heat injury during floral development in cowpea (*Vigna unguiculata* (L.) Walp.). *American J. Bot.* **79**: 784-91.
- Ali, Y.; Hussain, F. and Shakur, A. 2004. Genotype and environment interaction in cowpea (*Vigna unguiculata* L.) for yield and disease resistance. *International J. Environ. Sci. Tech.* **1**: 119-23.
- Anyia, A. O. and Herzol, H. 2004. Water-use efficiency, leaf area and leaf gas exchange of cowpea under mid-season drought. *European J. Agron.* **20**: 327-39.
- Asian Vegetable Seeds – EvergreenSeeds. <http://www.evergreenseeds.com/wingedbean.html>
- Awonaike, K. O.; Kumarasinghe, K. S. and Danso, S. K. A. 1991. Nitrogen assimilation and distribution in field-grown cowpea at various growth stages. *Soil Sci. Soc. Am. J.* **55**: 81-85.
- Bailey, L. H. 1953. *Standard Encyclopedia of Horticulture*, the MacMillan Co., New York.
- Bala Subramanian, V. and Maheswari, M. 1992. Compensatory growth responses during reproductive phase of cowpea after relief of water stress. *J. Agron. Crop Sci.* **14**: 361-64.
- Barrett, R. P.; Simon, J. E. and Janick, J. 1997. Legume species as leaf vegetables. *In: Advances in New Crops*. Timber Press, Portland.
- Beech, D. F. and Charles-Edwards, D. A. 1984. Comparison of growth and development of two selections of guar, *Cyamopsis tetragonoloba* (L.) Taub. with contrasting branching pattern. *Australian J. Plant Physiol.* **11**: 385-93.

- Charles-Edwards, D. A. and Beech, D. F. 1984. On the ordered development of plants 3. Branching by grain legume *Cyamopsis tetragonoloba* (guar). *Annals Bot.* **54**: 673-79.
- Chow, K. K. and Price, T. V. 1989. Biomass and flower production of winged bean in a nutrient film (NFT) hydroponic system. *Plant Soil.* **113**: 85-92.
- Chozin, M.; Garner, J. O. and Watson, C. E. 2002. Traits associated with drought resistances in cowpea. *J. Ilmu-Ilmu Pertanian Indonesia* **4**: 84-88.
- Crauford, P. Q.; Summerfield, R. J.; Ellis, R. H. and Roberts, E. H. 1997. Photoperiod, temperature, and the growth and development of cowpea. *In: Advances in Cowpea Research*. Singh B. B., Mohan Raj D. R., Dashiell K. E. and Jackai L. E. N., (Eds). IITA & JIRCAS. IITA, Ibadan, Nigeria, pp. 75-86.
- CRN. India. Guar or Cluster bean. <http://www.crnindia.com/commodity/guar.html>
- Davis, D. W.; Oelke, E. A.; Oplinger, E. S.; Doll, J. D.; Hanson, C. V. and Putnam, D. H. 1991. Cowpea. <http://www.hort.purdue.edu/NEWCROP/AFCM/cowpea.html>
- Douglas, L. A and Weaver, R.W. (1989). Partitioning of biologically fixed nitrogen in cowpea during pod development. *Plant Soil.* **116**: 129-31.
- Douglas, L. A and Weaver, R. W. 1993. Distribution of fixed-N and nitrate-N during pod development. *Plant Soil.* **155-156**: 353-54.
- Dow el-madina, I. M. and Hall, A. E. 1986. Flowering of contrasting cowpea (*Vigna unguiculata* (L.) Walp.) genotypes under different temperatures and photoperiods. *Field Crop Res.* **14**: 87-104.
- Eagleton, G. E.; Khan, T. N. and Erskine, W. 1985. Winged bean (*Psophocarpus tetragonolobus* (L.) DC.). *In: Grain Legume Crops*. Summerfield R. J. and Roberts E. H., (Eds). Collins. London, pp. 624-57.
- Emongor, V. 2007. Gibberellic acid (GA<sub>3</sub>) influences on vegetative growth, nodulation and yield of cowpea (*Vigna unguiculata* (L.) Walp. *J. Agron.* **6**:509-17.
- Fageria, N. K. 1992. *In: Maximizing Crop Yield*. CRC Press, pp. 242-43. <http://book.google.co.in>
- FAO. Ecocrop. *Cyamopsis tetragonoloba*. <http://ecocrop.fao.org>
- Garg, B. K. and Burman, U. 2002. Physiology. *In: Guar in India*. Kumar D. and Singh N. B., (Eds). Scientific Publishers, Jodhpur, India, pp. 63-84.
- Grantz, D. A. and Hall, A. E. 1982. Earliness of an indeterminate crop, (*Vigna unguiculata* (L.) Walp., as affected by drought, temperature, and plant density. *Australian J. Agric. Res.* **33**: 531-40.
- Guar Gum. [http://www.guargum.biz/guargum\\_faqs.html](http://www.guargum.biz/guargum_faqs.html)
- Hadley, P.; Roberts, E. H.; Summerfield, R. J. and Minchin, F. R. 1983. A quantitative model of reproductive development in cowpea (*Vigna*



*unguiculata*) in relation to photoperiod and temperature and implication for screening germplasm. *Annals Bot.* **51**: 531-44

Hall, A. E. and Grantz, D. A. 1981. Drought resistance of cowpea improved by selecting for early appearance of mature pods. *Crop Sci.* **21**: 461-64.

Hall, A. E.; Mutters, R. G.; Hubick, K. T. and Farquhar, G. D. 1990. Genotypic differences in carbon isotopic discrimination by cowpea under wet and dry field conditions. *Crop Sci.* **30**: 300-05.

Higuchi, M.; Fukumoto, Y. and Iwai, K. 1988. Appearance of lectins in winged bean pods during seed development after flowering. *J. Agric. Food Chem.* **36**: 534-36.

ICAR News Success Story. <http://www.icar.org.in/node/680>.

Information on Moth bean. <http://www.agricultureinformation.com>

Ismail, A. M. and Hall, A. E. 1992. Correlation between water use efficiency and carbon isotope discrimination in diverse cowpea genotypes and isogenic lines. *Crop Sci.* **32**: 7-12.

Ismail, A. M. and Hall, A. E. 1993. Inheritance of carbon isotope discrimination and water-use efficiency in cowpea. *Crop Sci.* **33**: 498-530.

Ismail, A. M. and Hall, A. E. 1998. Positive and negative effects of heat-tolerance genes in cowpea. *Crop Sci.* **38**: 381-90.

Ismail, A. M. and Hall, A.E. 1999. Reproductive-stage heat tolerance, leaf membrane thermostability and plant morphology in cowpea. *Crop Sci.* **39**: 1762-68

Jamadagni, B. M.; Bendale, V. W.; Joshi, M. W. and Kore, V. N. 2003. Effect of water stress on pod development and yield realisation in cowpea (*Vigna unguiculata* L. Walp.). *Orissa J. Hortic.* **31**: 47-50.

Kaushik, A. M. and Laghari, N. 2007. Hidden potential of cowpea. <http://www.dawn.com/2007/01/01/abr5.htm> January 01, 2007

Khan, T. N. 1976. Papua New Guinea, a centre of genetic diversity in winged bean (*Psophocarpus tetragonolobus* [L.] DC.). *Euphytica.* **25**: 693-706.

Kharb, R. P. S.; Singh, V. P. and Tomar, Y. S. 1987. Moth bean [*Vigna aconitifolia* (Jacq.) Marechal]- a review. *Forage Res.* **13**: 113-32.

Khor, Hun-Teik. 1985. Lipids and fatty acid composition of developing winged bean seeds. *Phytochem.* **24**: 856-57.

Kort, A. A. and Cadwell, J. B. 1984. Characteristics of the proteins of the tubers of the winged bean (*Psophocarpus tetragonolobus* (L.) DC.). *J. Sci. Food Agric.* **35**: 304-13.

Lush, W. M. and Evans, L. T. 1980. Photoperiodic regulation of flowering in cowpea (*Vigna unguiculata* (L.) Walp.). *Annals Bot.* **46**: 719-25.

- Lynd, J. A.; Lurlap, C. and Fernando, B. L. 1983. Perennial winged bean yield and nitrogen fixation improvement with soil fertility treatment of a Typic Eutruxox. *J. Plant Nutrition*. **6**: 641-56.
- Marfo, K. O. and Hall, A. E. 1992. Inheritance of heat tolerance during pod set in cowpea. *Crop Sci.* **32**: 912-18.
- Martin, F. W. and Delpin, H. 1978. Vegetables for the hot humid tropics. Part 1. The winged bean (*Psophocarpus tetragonolobus*). USDA, Agric. Res. Service. Louisiana, New Orleans. pp. 1-22.
- Mishra, S. P. 1976. Studies on genetic variability and character association in Moth bean (*Vigna aconitifolia* (Jacq.)). *Andhra Agric. J.* **22**: 166-75.
- Motior M. R.; Wan Mohamad, W. O.; Wong, K. C. and Shamsuddin, Z. H. 1998. Nitrogen accumulation and partitioning by winged bean in response to support system. *Exp. Agric.* **34**: 41-53.
- Mutters, R. G. and Hall, A. E. 1992. Reproductive responses of cowpea to high temperature during different night periods. *Crop Sci.* **32**: 202-06.
- Mutters, R. G.; Hall, A. E. and Patel, P. N. 1989. Photoperiod and light quality effects on cowpea floral bud development at high temperatures. *Crop Sci.* **29**: 1501-05.
- N.A.S., 1975. *The Winged Bean. A high-Protein Crop for the Tropics*. National Academy Press, Washington D.C., pp. 1-44.
- N.A.S., 1981. *The Winged Bean. A high-Protein Crop for the Tropics*. 2<sup>nd</sup> Edition. National Academy Press, Washington D.C., pp. 1-40.
- Narain, P.; Singh, R.S. and Kumar, D. 2001. Droughts and dew bean productivity in northwestern Rajasthan, India. <http://digitalcommons.unl.edu/droughtnews/28>.
- Nene, Y. L. 2006. Indian pulses through the millennia. *Asian Agri-History*. **10**: 197-202.
- Nielsen, C. L. and Hall, A. E. 1985b. Responses of cowpea (*Vigna unguiculata* [L.] Walp.) in the field to high night temperatures during flowering. II. Plant responses. *Field Crop Res.* **10**: 181-96.
- Pate, J. S.; Atkins, C. A.; White, S. T.; Rainbird, R. M. and Woo, K. C. 1980. Nitrogen nutrition and xylem transport of nitrogen in ureide-producing grain legumes. *Plant Physiol.* **65**: 961-65.
- Pate, J. S.; Peoples, M. B. and Atkins, C. A. 1983. Post-anthesis economy of carbon in a cultivar of cowpea. *J. Exp. Bot.* **34**: 544-62.
- Patel, P. N. and Hall, A. E. 1990. Genotypic variations and classification of cowpea for reproductive responses to high temperatures during long photoperiods. *Crop Sci.* **30**: 614-21.
- Peksen, E. 2007. Yield performance of cowpea (*Vigna unguiculata* L. Walp.) under rainfed and irrigated conditions. *International J. Agric. Res.* **2**: 391-96.



- Peoples, M. B.; Atkins, C. A.; Pate, J. S. and Murray, D. R. 1985. Nitrogen nutrition and metabolic interconversions of nitrogenous solutes in developing cowpea fruits. *Plant Physiol.* **77**: 382-88.
- Peoples, M. B.; Pate, J. S. and Atkins, C. A. 1983. Mobilization of nitrogen in fruiting plants of a cultivar of cowpea. *J. Exp. Bot.* **34**: 563-78.
- Peoples, M. B.; Pate, J. S.; Atkins, C. A. and Murray, D. R. 1984. Economy of water carbon and nitrogen in developing cowpea fruit. *Plant Physiol.* **77**: 142-47.
- Qazi, A. K. and Caesar, K. 1989. Effect of floral bud and young pod removal on development and yield in winged bean. *Tropical Grain Legume Bulletin No.* 36, pp. 24-30.
- Quadir, I. and Ahmad, S. 2009. DAWN.COM. <http://finance.indiamart.com/markets/comodity/guar.html>.
- Quin, F. M. 1997. Introduction. In: Advances in cowpea research. (B. B. Singh, D. R. Mohan Raj, K. E. Dashiell and L. E. N. Jackai, eds.). IITA & JIRCAS. IITA, Ibadan, Nigeria. pp. IX-XV.
- Rathore, B. S. and Chippa, H. P. 1996. Varietal interaction of mothbean to rhizobium inoculation. *Indian J. Pulses Res.* **9**: 55-58.
- Roberts, E. H.; Summerfield, R. J.; Minchin, F. R.; Stewart, K. A.; Stewart, W. and Ndunguru, B. J. 1978. Effect of air temperature on seed growth and maturation in cowpea. *Annals. Applied Biol.* **90**: 437-46.
- Ryle, G. J. A.; Powell, C. E. and Gordon, A. J. 1979. The respiratory cost of nitrogen fixation in soybean, cowpea and white clover I. Nitrogen fixation and the respiration of the nodulated roots. *J. Exp. Bot.* **30**: 135-44.
- Salunkhe, D. K. and Kadam, S. S. 1998. Cluster bean. In: *Handbook of Vegetable Science and Technology: Production, Composition, Storage and Processing*. Marcel Dekker Inc. New York, pp. 477-79.
- Schiavinato, M. A. and Válio, I. F. M. 1996. Influence of staking on development of winged bean plants. *R. Bras. Fisiol. Veg.* **8**: 99-103.
- Sheoran, I. S.; Luthra, Y. P.; Kuhad, M. S. and Singh, R. 1982. Clusterbean-A ureide- or amide-producing legume? *Plant Physiol.* **70**: 917-18.
- Shouse, P. J. 1979. Effect of water deficit on the growth, yield and water use of field-grown cowpea crop. Dissert. Abst. Int. B, **40**: 1992-93.
- Shouse, P. J.; Dasberg, S.; Jury, W. A. and Stolzy, L. H. 1981. Water deficit effects on water potential, yield and water use of cowpeas. *Agron. J.* **73**: 333-36.
- Singh R.S.; Rao, A.S.; Joshi, N.L and Ramakrishna, Y.S. 2000. Evaporation rate and water utilization of moth bean under two soil moisture conditions. *Annals Arid Zone.* **39**: 1-8.
- Soni, C. P. 1992. 'Physiological analysis of yielding ability in moth bean (*Vigna*

*aconitifolia* (Jacq.) Marechal'. M. Sc. (Agric) Thesis, SKN College of Agriculture, Rajasthan Agricultural University, Bikaner, Rajasthan, India.

Srivastava, J. P. and Soni, C. P. 1995. Physiological basis of yield in moth bean [*Vigna aconitifolia* (Jacq.) Marechal] under rainfed conditions. *J. Agron. Crop Sci.* **174**: 73-77.

Stafford, R. E. 2008. Dry matter accumulation in different guar genotypes under irrigated and dryland conditions. *J. Agron. Crop Sci.* **158**: 38-58.

Stafford, R. E. and NcMichael, B. L. 2008. Effect of water stress on yield components in guar. *J. Agron. Crop Sci.* **166**: 63-68.

Talwar, H. S.; Soni, M. L.; Beniwal, R.K.; Yadava, N. D.; Singh, J. P.; Rathore, V. S. and Kumar, S. 2008. Crop physiological approach to evaluate drought-resistant traits in clusterbeab (*Cyamopsis tetragonoloba*). *Indian J. Agric. Sci.* **78**: 413-17.

Tarafdar, J. C. and Kumar, D. 2003. Moth bean (*Vigna aconitifolia*) cultivars compared for root nutrient uptake efficiency in arid NW India. *J. Arid Environ.* **55**: 215-22.

The Hindu, 2002. Winged bean, multi-purpose tropical legume. The multi-purpose tropical bean yields tasty pods, which are rich in protein and vitamin A. September 26, 2002. <http://www.hinduonnet.com/set/2002/09/26>.

Thomas Jefferson Agricultural Institute. Cowpea. A versatile legume for hot, dry conditions. <http://www.jeffersoninstitute.org/pubs/cowpea.shtml>.

Thompson, A. E. and Haryono, S. K. 1980. Winged bean: Unexploited tropical food crop. *Hort. Sci.* **15**: 233-38.

Undersander, D. J.; Putnam, D. H.; Kaminski, A. R.; Kelling, K. A.; Doll, J. D.; Oplinger, E. S. and Gunsolus, J. L. <http://www.hort.purdue.edu/newcrop/AFCM/guar.html>.

USDA National Nutrient Database for Standard Reference, Release 23 (2010). [http://www.nal.usda.gov/fnic/foodcomp/cgi-bin/list\\_nut\\_edit.pl](http://www.nal.usda.gov/fnic/foodcomp/cgi-bin/list_nut_edit.pl)

USDA. 2005. (Cited by Brink, M. and Jansen, P. C. M. *Vigna aconitifolia* (Jacq.) Marecchal. In: *Plant Resources of Tropical Africa 1. Cereals and Pulses*. Brink M. and Belay G., (Eds). PROTA Foundation, Wageningen, Netherlands/Backhuys Publishers, Leiden, Netherlands/CTA, Wageningen, Netherlands, pp. 200-03).

Valenzuela, H. and Smith, J. 2002. Green manure crops: Cowpea. CTAHR. <http://www2.ctahr.hawaii.edu>.

Warrag, M. O. A. and Hall, A. E. 1984. Reproductive response of cowpea (*Vigna unguiculata* (L.) Walp.) to heat stress: II. Response to night air temperature. *Field Crops Res.* **8**: 3-16.

Watt, G. 1889. A Dictionary of Economic Products of India. Cosmo Publications, Delhi, India. (reprinted 1972).



Weaver, W. W. 2007. Introducing the Hunan winged bean. Motherearthnews.com. June/July 2007. <http://www.motherearthnews.com/Real-Food/2007-06-01/Hunan-Winged-Bean.aspx>

Weil, R. R. and Belmont, G. S. 1991. Dry matter and nitrogen accumulation and partitioning in field grown winged bean. *Exp. Agric.* **27**: 323-328.

Wien, H. C. and Ackah, E. E. 1978. Pod development period in cowpeas: Varietal differences as related to seed character and environmental effect. *Crop Sci.* **18**: 791-794.

Wikipedia. The Free Encyclopedia. Cowpea. <http://en.wikipedia.org/wiki/Cowpea>.

Wikipedia. The Free Encyclopedia. Mothbean. <http://en.wikipedia.org/wiki/Mothbean>.

Winged bean. [http://www.absoluteastronomy.com/tropics/Winged\\_bean](http://www.absoluteastronomy.com/tropics/Winged_bean).

Yanagy, S. O. 1983. Properties of the winged bean, (*Psophocarpus tetragonolobus*) protein in comparison with soybean (*Glycine max*) and common bean (*Phaseolus vulgaris*) proteins. *Agric. Biol. Chem.* **47**: 2273-80.

Zonal Agricultural Research Station, Shilapur. Dry land Technology. Integrated Nutrient Management. <http://kvksolapur.org/Inn-Technologies-1.htm>. ●

## **CHAPTER 12**

### **Vegetable Legumes**

**P**ulses are mostly used in the form of split grains and dry seeds are also consumed as snacks after boiling in water. Green pods and green seeds are also consumed as vegetables and soups (Morton, 1976), canned pulses are marketed in certain parts of the world. Different legumes crops have different characteristics and can be grown successfully in different agro-climatic zones. The pulses are mostly used as mature seed in different forms, but most of the legumes are also used as vegetable. Some of the legumes which are used as vegetables are listed in Table 1.

These legumes belong to body building food groups as they make the human body healthy. These are considered to be the better substitutes of meat or fish. When the pods or green seed are picked before physiological maturity, then they are used as vegetable and eaten before the seeds lose their green colour. At this stage the seed is more nutritious than the dry seed because it has more protein, sugar and fat in addition, which are easily digestible. Green seeds are having considerably lower quantities of sugars that produce gas (flatulence). Nevertheless, the dried seeds contain more minerals. Nutritive values of green and mature pigeonpea seeds are given in Table 2.

Though the vegetable pigeonpea takes longer time to cook than vegetable pea, it is much more nutritious on fresh weight basis. It has greater edible protein, more protein, carbohydrates, fibre and fat than green pea. It has more minerals and much more vitamins (469 vs. 83 Vitamin A, 0.3 vs, 0.01 Vitamin B<sub>2</sub> and 25 vs, 9 Vitamin C/100g). The vegetable pigeonpea cultivars are desired to have long pods, and nine large seeds that can be easily removed. It is also reported that pod color is not related to the taste, but its sweetness is a desirable character. The white coloured seeds are preferred as compared to colored pods/seeds. The yield of green pods are high as 11 tonnes ha<sup>-1</sup> can be obtained in five pickings and farmers get early money of their harvest and need not have to wait till maturity and threshing.

Sprouted seeds are also a good source of vitamin C. The vitamin C content of sprouted beans, pea, lentil, mung, and chickpea has been found to be almost as high as that in lemon and orange juice. In presence of vitamin C human body uses iron properly. Availability of iron, zinc and



Table 1. The legumes which are also used as vegetables

Crop	Botanical name	Uses
Cowpea	<i>Vigna unguiculata</i>	Good source of protein, young pods are used as vegetables, and in salad, mature seeds cooked and eaten as vegetable or added to soup and stews
Green pea	<i>Pisum sativum</i>	Good source of protein and fibre. Premature pods or seeds are eaten fresh or as vegetable, matured grains are used as cooked dal or used in powder form as besan
Mungbean	<i>Vigna radiata</i>	Green pods eaten as vegetable matured seeds are eaten as whole or split, can be roasted, ground into flour and used for various preparations. Sprouted seeds are very common in use
Urdbean	<i>Vigna mungo</i>	Immature green pods are used as vegetables, eaten whole seed or splits in to dal, seeds may be roasted and ground flour is used in many preparations
Pigeonpea	<i>Cajanus cajan</i>	Good source of protein, young pods can be used as vegetables; matured seeds are used as dal, and can be used as sauce after mixing with seasoning and paste
Kidney bean	<i>Phaseolus vulgaris</i>	Immature pods can be used as salad, dried seeds cooked and eaten as vegetable or added to soups and stews
Winged beans	<i>Psorphocarpus tetragonolobus</i>	Pods are eaten at all stages of maturity; dried seeds are soaked and boiled, roasted or curried
Chickpea	<i>Cicer arietinum</i>	Used as green seed for chholas, samosas and various other preparations. Matured seeds are used as whole or split into dal, dried in powdered form (besan) and used for different preparations. Sprouted seeds are also common in use
Lablab bean	<i>Dolichas sp. Lablab niger Medikus</i>	Good source of protein and fibre, young pods are eaten as vegetable, mature pods are soaked in water and dried
Ground nut	<i>Arachis hypogaea</i>	Very good source of protein and oil, vitamins, roasted and eaten as snacks used in soup and stews, added to cakes, biscuits and snacks
Soybean	<i>Glycine max</i>	Good source of protein, oil, minerals and fibre, used as soysouce, soy milk, curd and paste

Source: FAO, 1991

calcium increases to maintain good health, strong bones and teeth and early wound healing. Nutritive values of mature and sprouted mungbean seeds are given in Table 3.

**Table 2.** Nutritional values of green and mature pigeonpea seeds on dry-weight basis

Constituent	Green seeds	Mature seeds
Protein (%)	21.0	18.8
Protein digestibility	66.8	58.5
Trypsin inhibitor (units/mg)	2.8	9.9
Starch (%)	44.8	53.0
Starch digestibility	53.0	36.2
Amylose inhibitor (units/mg)	17.3	26.9
Soluble sugars	5.1	3.1
Flatulence factor (g 100g-1 soluble sugar)	10.3	53.5
Crude fibre (%)	8.2	6.6
Fat (%)	2.3	1.9
Minerals and trace elements (mg 100 g <sup>-1</sup> )		
Calcium	94.6	120.8
Magnesium	113.7	122.0
Copper	1.4	1.3
Iron	4.6	3.9
Zinc	2.5	2.3

Source: Price, 1990

**Table 3.** Nutritive value of mature raw and sprouted seeds of mungbean

Nutrients constituents/units	Raw seed (100 g <sup>-1</sup> seed)	Sprouted seed (100 g <sup>-1</sup> seed)
Food energy (cal.)	384.00	313.00
Carbohydrates (g)	67.50	58.80
Protein (g)	27.10	33.80
Lipid (g)	1.46	1.77
Minerals		
Calcium (mg)	132.00	169.00
Phosphorus (mg)	380.00	570.00
Potash (mg)	1150.00	1990.00
Iron (mg)	8.60	11.60
Sodium (mg)	6.70	45.20
Vitamins		
A (IU)	89.00	177.00
Thiamin (mg)	0.42	1.16
Riboflavin (mg)	0.23	1.16
Niacin (mg)	2.91	7.08
Ascorbic acid (mg)	6.00	169.00

Adapted from Adams (1975) and Fordham *et al.* (1975).



## REFERENCES

- Adams, C. F. 1975. Nutritive value of American foods in common units. *Handbook No. 456*. United Department of Agriculture.
- FAO. 1991. Corporate Document Repository. Leaflet No. 16-1991-Legumes. <http://www.fao.org/WAIRdocs/x5425e/x5425e0g.htm>
- Fordham, J. R.; Wells, C. E. and Chen, L. H. 1975. Sprouting of seeds and nutrient composition of seeds and sproutes. *J. Food. Sci.* **40**: 552-56.
- Morton, J. F. 1976. The pigeon pea (*Cajanus cajan* Millsp.), a high-protein, potential legume. *Hort. Sci.* **11**: 11-19.
- Price, M. L. 1990. Pigeon pea. ECHO Technical Note. ECHO, 17391 Durrance Rd. North Ft. Myer FL 33917, USA. <http://www.echonet.org/> ●

## **CHAPTER 13**

### **Ideal Plant Type for Higher Yield**

**T**he crop ideotype has been defined as an idealized plant type with a specific combination of traits deemed favourable for photosynthesis, growth and grain yield (Donald, 1968). To obtain high yield potential, increased emphasis, particularly in India, is being given to plant type (Jain, 1975). The idea of reconstructing plant type has been borrowed from the high yielding wheat (Asana, 1968; Donald, 1968) and rice cultivars (Yoshida, 1972). Pulses, in general, are indeterminate types and sensitive to photo-thermo periods. They also produce more flowers, but pod setting is poor. The photosynthetic rate at pod formation stage and thereafter declines at a faster rate, and it is also coupled with poor nitrogen supply. Therefore, leaf senescence is also a common problem during later phase of crop growth. The pulses are grown in various agro-climatic zones with different maturity durations and genotype  $\times$  environment interaction plays very important role in determining crop growth and yield. Therefore, specific plant characters for a specific cropping zone are the pre-requisite for higher yield realization. The sole cropping and inter-cropping systems require different plant types.

In pulses, new plant type refers to shorter and more compact plants with a high harvest index, less sensitive to photo-thermoperiod, earlier maturity and more determinate growth habit. These types of plants are more suited to short summer season, high plant populations and multiple cropping programmes. For maximum grain production, vegetative growth should be terminated with flowering and assimilates be channeled into produce at the time of pod development (Saini and Das, 1979; Pawar and Bhatia, 1980). It is also suggested that plants should have small leaves and upright branch (Chandel *et al.*, 1980). If a high pod set is obtained on the first and second flush of flowering (synchronous flowering habit), the number of pickings and labour cost is reduced. Non-shattering habits of pods is must for higher grain yield/day (less duration; yield based on duration of crop) and not necessarily per hectare. The lobed leaf urd bean is found as a potential means of obtaining greater penetration of sunlight into the canopy (AVRDC, 1985). There are reports that long duration cultivars with more flushes of flowering, yield more even under unfavourable conditions (Chowdhury and Hague, 1977). Panwar and Thakur (1995) and Kumar *et al.* (2003) have also noticed higher yield with late maturing type having more flushes.



Abiotic stress such as drought (terminal or intermittent), heat (heat shock and moderate heat), and cold (freezing or chilling) are the most important stresses in pulses, and the ideal plant types may be necessary to fulfill the need of the farmers. It is also essential to have genotypes with high and stable yield, higher nodulation and N-fixation capacity, disease and pests resistant. Early seedling vigour with fast ground cover, early flowering, podding with multi seeded types and small leaflets with high root length density may be developed for drought and heat tolerance. Physiological traits such as high WUE, stomatal frequency, chlorophyll content, light use efficiency, photosynthetic rate, transpiration efficiency, turgor maintenance capacity, stored photosynthates remobilization with pollen viability and high pod setting may be incorporated to develop an ideal plant type for abiotic stresses as suggested by Toker *et al.* (2005).

No single plant type will be optimum for all production situations, local climatic conditions (rainfall, temperature, duration and intensity of sunlight). Environmental condition, cropping season, cultural practice, disease and pest, and labour cost, etc., needs consideration in evolving a plant type for a specific breeding programme. The degree of indeterminate growth and photo-insensitivity needs more consideration for higher yield (Na Lampang *et al.*, 1988).

Our aim for plant type is to conceptualize a plant where the plants yield may be maximized and under crop community the yield reduction should also be minimized. Plant types of pigeonpea and chickpea, for different cropping systems, are given below.

### Chickpea Plant Type

Traditionally chickpea has been categorized as a rainfed crop. Hence under rainfed condition a small plant density is desirable to enable plants to reach maturity before the soil moisture is depleted, with a provision that the plant has the capacity to grow more if more water becomes available. If water becomes available at the reproductive stage, it may be detrimental to seed yield, and more over at such stage the primary, secondary and even late order branches are not formed and yield is reduced. Under low water availability, a low plant population along with a capacity to respond if available water increases due to occasional rain, would be desirable. However, for assured irrigated area, plants with less vigorous vegetative growth will be the right plant type. Sinha (1977) suggested that a relatively erect type with shorter internodes might be a suitable ideotype of chickpea. Efforts should be made to breed for erectness combined with tall growth by hybridization between conventional spreading and tall types (Bahl, 1980). Many tall type progenies have been obtained, but they maintain poor harvest index because their internodal length is more and substantial amount of assimilates are spent on structural parts of the plants. Reducing internodal length may enhance harvest index in chickpea. It has also been suggested

that consideration should also be given for extra large seeded *kabuli* and medium sized *desi* types based on local preference.

### Chickpea Plant for Rainfed Condition

- Semi-erect growth habit, rapid ground cover.
- More number of primary and secondary branches and less number of tertiary branches.
- Strong, deep and profuse root development.
- Small, but more number of leaflets per leaf.
- Low leaf senescence rate.
- Double poddedness to provide stability.
- Seed size; small to medium.
- High biomass and harvest index.
- For northern region of the country, medium maturity period, i.e., 130-140 days; and for southern and central regions <100 days.

### Pigeonpea Ideotype

Different maturity group (early, medium and long duration) are grown under different agro-climatic condition and different cropping systems. Early types are mostly grown as sole crop, where as medium and long duration varieties are grown under mixed cropping/inter cropping. The medium and long duration varieties of pigeonpea are grown along with the crops like sorghum, millets, maize, groundnut, soybean, cotton and castor. Therefore, ideal pigeonpea varieties should have initial low growth rate and should maintain higher growth rate after the harvest of companion crop. These varieties have high biomass production (15-20 tonnes ha<sup>-1</sup>) with harvest index of 10-52% depending on genotype, environment and agronomic practices. In general, compared to early types late types of pigeonpea varieties have low harvest index and fruiting occurs on the top of the plants with short fruiting branches.

In early types, the limited biomass production is a yield limiting factor, they mature early (120-150 days) with higher harvest index, but further enhancement of harvest index does not guarantee high productivity. The plant types needs to be conducive to efficient partitioning of photoassimilates and lowered competition for intercropping and plant population. Seed yield is positively correlated with pods per plant, primary branches, secondary branches and number of pod in clusters per plant. Earliness is strongly and positively correlated with high harvest index.

A new plant type of pigeonpea should possess early maturity, photo-thermo insensitivity, short stature and determinate to semi-determinate growth habit with higher harvest index and faster growth rate. For the medium and longer duration varieties, efforts should be made to reduce structure with open canopy to increase fruiting sites. It is desirable to



develop plant type with 4-5 long upright fruiting branches originating from the base with the maximum height of 1.5 to 2 meter, having cleistogamous flowers, long pods with 4-5 round and bolder seeds.

Intermediate plant type should be relatively less photoperiod and temperature sensitive, having maximum height of 1 meter with few secondary branches, large number of nodes, short internodes, small leaves, fewer seeds per pod with test weight of 8-10 g per 100 seeds along with deep rooting system and insect resistant; particularly pod borer, and other resistant to other diseases.

In pigeonpea, the hybrids plays a very important role in removing the barrier of yield and its plant type will further strengthen our claim for better yield. There is a need to further exploitation of hybrid vigour in this crop. In hybrids the intra-plant competition for photosynthates increases due to increased synchronous fertilization and pod set and, therefore, plant needs more current photosynthates as well as stored photosynthates to meet the demand of effective sinks (flower and pod setting). The rate of grain filling should be quick as this property may lead to increased seed yield. The plant physiologist should work hand in hand to further enhance the exploitation of hybrid vigour.

### **Pigeonpea for Sole Crop (Early Pigeonpea Types)**

- Early vigour
- Crop duration 120 days  $\pm$  10 days.
- Relatively more determinate type with synchronous maturity.
- Semi-erect with 5-7 branches.
- More stay green with higher photosynthetic rate during grain development.
- Better C:N ratio during pod filling with faster grain growth. UPAS-120 is nearing to plant type that needs improvement with enhancing biomass, and there is a scope for yield enhancement. Yield plateau has not been reached.
- Fruiting body length should be 30-40 cm.
- 30 pods branch<sup>-1</sup>, i.e. 150-200 pods plant<sup>-1</sup>.
- Wilt, sterility mosaic and phytophthora resistant.
- Seed size should be 10-12 g per 100 seeds.

In pigeonpea, early maturing hybrids are being released so that it can be fitted in the pigeonpea-wheat rotation and such hybrids are being utilized for multiple cropping systems. The flowering and fruiting should be in a period of low relative humidity so that insect pest attack could be minimized and better harvest index is achieved.

### Late Maturing Pigeonpea for Intercropping

- Initial slow growth.
- Tolerant to drought and water logging and terminal drought.
- Higher biomass 8-10 t ha<sup>-1</sup> with higher photosynthetic rate and leaf area durations
- Photo thermo insensitive plants, bearing temperature fluctuation capacity during grain development.
- Less flowers with higher pod set percentage.
- More primary and secondary branches with upright habit.
- Early flower flushes should be avoided and capacity to set pods even during foggy weather is a prerequisite.
- High harvest index (30%).
- Should have resistance to wilt sterility mosaic, phytophthora stem blight and other diseases. MAL 13 is a suitable genotype while Narendra Arhar-1 is a compact type and can be improved for better harvest.

Ideotypes for some other pulses are given below:

### *Vigna group* (mungbean) Spring/Summer Season

- It should be determinate type; crop duration should not be more than 55 days.
- 2-3 upright branches with lower branch angle.
- Effective pod bearing nodes more in number, starting from 2<sup>nd</sup> or 3<sup>rd</sup> node from the base with 5-8 pods cluster<sup>-1</sup>.
- 8-12 seeds pod<sup>-1</sup>; without losing seed size.
- Test weight 3-5g 100<sup>-1</sup> seed.
- Synchronous maturity.

### *Vigna group* (mungbean) *Kharif* Season

- Indeterminate growth habit.
- Photo-thermo insensitive varieties with resistance to yellow mosaic virus and *Cercospora* leaf spot.
- Primary and secondary branches should be having higher pod bearing capacity.
- Tolerant to pre-harvest sprouting of seeds.
- G x E interaction is very important.
- Few flowers with higher pod set.
- Pod photosynthesis is an important traits and seed filling rate should be higher (no gap between seeds in pods).
- Lower leaf senescence rate with higher leaf N content.



### Pea

- Plant should be early maturing type (100 days duration).
- Dwarf plant with a height of 90-100 cm.
- Stem should be stiff to minimize lodging.
- More tendrils to enhance disease resistance to powdery mildew.
- Synchronous maturity habit.
- HI should be >30%.

### Lentil

- Semi erect plant type.
- More number of primary branches.
- Relatively higher biomass with higher harvest index.

## REFERENCES

- Asana, R. D. 1968. Growth habits of crops of non irrigated areas: Important characteristics of plant type. *Indian Farming* **18**: 25-27.
- AVRDC. 1985. Progress Report, 1983, Asian Vegetable Research and Development Centre, Shanhua, Tawain.
- Bahl, P. N. 1980. Kabuli and desi introgression and genesis of new plant types in chickpea. In: *Proceedings of International Workshop on Chickpea Improvement*. 28<sup>th</sup> February-2<sup>nd</sup> March, 1978, ICRISAT, Patancheru, Hyderabad, India, pp. 75-80.
- Chandel, K. P. S.; Joshi, B. S. and Pant, K. C. 1980. Breeding moong bean (*Vigna radiata* (L) Wilczek) for photosensitivity, high yield and field resistant to yellow mosaic virus. *Tropical Grain Legume Bulletin*. **18**: 29-32.
- Chowdhury, S. K. and Haque, M. N. 1977. Stability performance of some green gram varieties. *Indian J. Agric. Sci.* **47**: 303-304.
- Donald, C. M. 1968. The breeding of crop ideotypes. *Euphytica* **17**: 385-403.
- Jain, H. K. 1975. Breeding for yield and other attributes in grain legumes. *Indian J. Gen. Plant Breeding* **35**: 169-87.
- Kumar; N.; Nandwal, A. S.; Lather, V. S.; Dahiya, B. S.; Sheoran, I. S.; Waldia, R. S. and Panwar, J. D. S. 2003. Studies on dry matter partitioning and yield variation in different varieties of chickpea. *Indian J. Plant Physiol.* (**Special Issue**): pp. 91-97.
- Na Lampang, A.; Pichitporn, S.; Singh, S and Vanikijmongkol, N. 1988. Mungbean growth pattern in relation to yield. Shanhua, Tiwan
- Panwar, J. D. S. and Thakur, A. K. 1994. Physiological and biochemical studies in VAM, *Rhizobium* inoculated mungbean plants under field condition in mycorrhizae, biofertilizers for future. *III National Conference on Mycorrhiza*, held at TERI, New Delhi, pp. 471-77.

Pawar, S. E. and Bhatia, C. R. 1980. The basis for grain yield differences in mungbean cultivars and identification of yield limiting factors. *Theoretical Applied Gen.* **57**: 171-75.

Saini, A. D. and Das, K. 1979. Studies on growth and yield of three mungbean cultivars. *Indian J. Plant Physiol.* **22**: 147-55.

Sinha, S. K. 1977. Food Legumes: Distribution, adaptability and biology of yield. Food and Agriculture Organization of the United Nations Plant Production and Protection Paper, No. 3, FAO, Rome.

Toker, C.; Ulgar, S.; Karhan; Canci, M.; Akdesir, H.; Rrtoy, N. and Cargerrgen. M. J. 2005. Comparison of some endogenous hormone level in different parts of chickpea. *Genetic Resources Crop Evolution.* **52**: 65-73.

Yoshida, S. 1972. Physiological aspects of grain yield. *Ann. Rev. Plant Physiol.* **23**: 437-64. ●



## **CHAPTER 14**

# **Challenges for Pulse Productivity: Physiological and Molecular Approaches**

Pulses are mostly grown under rainfed conditions and face a number of abiotic and biotic stresses. Drought, temperature extremes, and salinity and alkalinity of soils are the most common abiotic stresses that pulses generally encounter. Globally approximately 22% of the agricultural land is saline (FAO, 2004) and area under salinity and drought is expected to increase further (Burke *et al.*, 2006). In field, crops are often exposed to multiple stresses. Therefore, the manner in which a plant senses and responds to different environmental stresses appears to be overlapping.

The abiotic stresses include terminal drought, high temperature during the reproductive stages, cold sensitivity during vegetative and flowering stages, and salinity and alkalinity throughout the crop period. These inflict major yield losses and instability in production and makes pulses less productive with unstable performance. Nutrient stress is another important abiotic stress causing yield losses to the extent of 30%. Consequently pulses are perceived as a crop of marginal farmers, laden with high risk and poor yield. Abiotic stresses adversely affect growth and productivity and trigger a series of morphological, physiological, biochemical and molecular changes in plants. We can observe a phenomenal changes in morphology and physiological process in plants such as decreased leaf area, leaf abscission, increased root:shoot ratio, enhanced root extension, cessation of growth, altered energy dissipation by crop canopy, closure of stomata, accumulation of proline, decrease in photosynthesis, decrease in nodulation and nitrogen fixing capacity, increase in wax content especially on leaf surfaces and sometimes induction in CAM (Crassulacean Acid Metabolism) physiology. It is known that environmental stresses result in an enhanced generation of reactive oxygen species (ROS) such as singlet oxygen ( $^1\text{O}_2$ ), super oxide radicals ( $\text{O}_2^-$ ), hydrogen peroxide ( $\text{H}_2\text{O}_2$ ) and hydroxyl radicals ( $\cdot\text{OH}$ ), which lead to oxidative stress at the cellular level. Excess ROS is produced primarily by photosynthetic and mitochondrial electron transport chains. ROS reacts with lipids, proteins and DNA molecules, resulting in lipid peroxidation, protein denaturation and DNA damage. To protect cells from detrimental effects, caused by reactive oxygen species under stress

conditions, plant tissues possess ROS scavenging enzymes such as superoxide dismutase (SOD), catalase, peroxidases, polyphenol oxidase, and a network of low molecular mass non-enzymatic antioxidants such as ascorbate, glutathione, phenolic compounds, tocopherols. For the regeneration of the active forms of the antioxidants, enzymes, viz. ascorbate peroxidase, dehydroascorbate reductase, glutathione reductase are further required. Metabolites such as ascorbate, glutathione and tocopherol control the levels of ROS in plant tissues. A major component of the defense mechanism is the ascorbate-glutathione cycle involving four enzymes, i.e. ascorbate peroxidase (APX), dehydroascorbate reductase, monodehydroascorbate reductase and glutathione reductase.

Responses of pulses in relation to drought and salinity have been reviewed from time to time (Panwar, 2003; Basu and Singh, 2003; Vadez *et al.*, 2006; 2007; Pooja Bhatnagar-Mathur *et al.*, 2008). Traits such as root length density, shoot dry matter, water-use efficiency, stomatal conductance, relative water content, transpiration efficiency, membrane stability, leaf temperature and osmotic potential have been used in the past to identify stress resistant genotypes and to understand the mechanism of abiotic stress resistance in pulses. Moisture deficit results in decreased water usage and consequently shoot dry matter, RWC, osmotic potential, and stomatal conductance, but leaf temperature and transpiration efficiency increased in stressed plants. The increased leaf temperature under stress condition is attributed due to the restricted transpirational cooling as a result of induced stomatal closure. Further, differences in stomatal conductance, leaf temperature,  $\Delta^{13}\text{C}$  and transpiration efficiency/water-use efficiency characterized genotypes that are physiologically more adapted to water deficit condition. It is observed that stomatal conductance, leaf temperature and  $\Delta^{13}\text{C}$  are promising physiological indicators for drought tolerance in faba beans, (Khan *et al.*, 2007) and mothbean.

## GENETIC IMPROVEMENT FOR DROUGHT TOLERANCE

In pulses various strategies, such as evaluation of genotypes for various component traits, selection of diverse parental genotypes; development and phenotyping recombinant inbred lines (RILs) using drought tolerant and drought susceptible types, have been employed for genetic improvement for drought tolerance. Studies related with genotyping of RILs with micro-satellite markers; analysis of phenotypic and genotypic data to develop a linkage map and to identify QTLs (quantitative trait loci) linked to important drought related traits are under progress under natural drought condition.

### Identification of QTLs for Root Traits

Despite the importance of root traits in drought avoidances and availability of germplasm with prolific root system, the breeding efforts



to improve root traits have been almost negligible. Molecular marker linked to major QTLs for root traits may greatly facilitate marker assisted selection for root traits in segregating generations. Over 500 SSR (Simple Sequence Repeat) markers have been developed in chickpea, and the chickpea genome map is rapidly expanding. ICRISAT has isolated and characterized root specific genes differentially expressed between ICC 4958 and Annegeri genotypes of chickpea. A set of 257 RILs were used and a SSR marker, TAA 170, was identified for a major QTL that accounts for 33.1 5% variation in root weight and root length. Based on the screening of mini-core collection, genetically and phenotypically more distant parents were identified for new mapping population. These include ICC 8261 and ICC 4958 for a large root system and ICC 283 and ICC 1882 for a small root system. Further work on such aspect is in progress in other laboratories (Jayshree *et al.*, 2005; Kashiwagi *et al.*, 2005; Kashiwagi *et al.*, 2007; Gaur *et al.*, 2008).

There are some problems in using QTLs as the introgression of genomic portions (QTLs) involved in stress tolerance often brings undesirable agronomic characteristics from the donor parents. This is because of lack of a precise knowledge of the key genes underlying the QTLs. Therefore, the development of genetically engineered plant by introduction and/or over expression of selected genes seems to be a viable option to hasten the breeding for improved plants.

## DROUGHT TOLERANCE

When a plant is subjected to abiotic stresses, a number of genes are turned on resulting in increased level of several metabolites and proteins, some of these considered to be responsible for conferring a certain degree of protection of plants from these stresses. A number of genes that responds to drought stress in chickpea have been described and their expression patterns are studied in order to elucidate their functions. Gene coding the lipid transfer proteins (LTP) and late embryogenesis abundance (LEA) proteins are reported to be important in chickpea under water stress. The induction of these genes is found to be not exclusive of osmotic stress caused by polyethylene glycol, as they also showed a significant up-regulation under high salinity. These genes were not responsive to exogenous abscisic acid (ABA) treatment. Cap LTP are mainly expressed in young tissues, messengers are more abundant in seedlings than in adult plants, and the transcript level decreases gradually as the age of epicotyl is advanced. It is suggested that LTPs might be involved in cuticle synthesis during early development stages. Cap LEA-1 and cap LEA-2 are markedly up regulated by NaCl treatment in every part of seedlings. The responses of these genes to high salinity have suggested their implications in protection of cellular functions from high ion concentration damage. The presence of LEAs in well watered; vegetative plant tissues suggest a new function for these proteins. Other cDNAs responsible for encoding

glyoxylases, proline rich protein and raffinose synthases have also been identified to be induced by water stress. Obviously, molecular basis to drought in plants are associated with changes in gene expression, and a large number of genes induced under drought are well identified.

Genetic engineering for developing stress tolerant plants based on the introgression of genes that are known to be involved in stress response and putative tolerance, might prove to be a faster track towards improving crop varieties. For beyond the initial attempt to insert “single action” genes engineering of the regulatory machinery involving transcription factors, has now emerged as a new tool for controlling the expression of many stress responsive genes. Nevertheless, the task of generating transgenic cultivars is not only limited to the success in transformation process, but also to proper incorporation of the stress tolerance in them. Evaluation of the transgenic plants under stress condition and understanding the physiological effect of the inserted genes at the whole plant level remains a major challenge (Pooja Bhatnagar-Mathur *et al.*, 2008).

### **Genes up Regulated and Down Regulated during Drought**

Differential screening of cDNA library made from PEG treated materials has yielded 47 clones, up or down regulated by water stress. The clones are sequenced and the corresponding deduced proteins have been analyzed. Both nucleotide and peptide sequences have been compared with other sequences in databanks and accordingly the cDNAs have been classified into 17 groups. Each group contained cDNAs with identical sequence, although different sizes. Cap LTP, Cap LEA-2, Cap LEA-1, Cap PRP, Cap PIP, Cap GLX-1, Cap 40 are found to be up regulated, whereas Cap BBP, Cap 28, Cap 46, Cap 50, Cap XET and Cap 30 are down regulated.

The DNA hybridization has shown that Cap LTP generates a unique hybridization band which indicates the probability of a single copy of the corresponding gene present in chickpea genome. The results of southern analysis by using either Cap LEA-1 or Cap LEA-2 as probes, gives the same DNA fragment after both ECoRI and HindIII digestion. These results showed cross hybridization between them owing to their similarity indicating probability of a single copy of each Cap LEA. Finally DNA hybridization using Cap GLX-1 as probe showed three different bands after digestion with ECoRI, and two bands with Hind III and Bam HI. This result suggested that at least two copies of corresponding genes are present in the chickpea genome.

### **Expression Patterns under Water Deficit Treatments.**

Water deficit induced by NaCl and PEG is reported to increased Cap LTP transcripts levels mainly in cotyledons, epicotyls, and mesocotyls. Presence of Cap LTP transcript has also been detected in roots after this



treatment. ABA treatment has no effect on transcriptional level of Cap LTP corresponding gene. Cap LEA-1 and Cap LEA-2 expression analysis indicates a slight increase in the transcript level mainly in epicotyls and roots after PEG treatment for 24 hours. NaCl induced water deficit markedly up regulates Cap LEA-1 and Cap LEA-2 gene expression. This induction has been observed in the whole seedling, although the mesocotyl contained the highest amount of transcript. Both high and low temperature and ABA treatment do not affect the gene expression in *Cicer arietinum* (Romo *et al.*, 2001). Water stress induced by PEG and NaCl down regulates the expression. NaCl stress up-regulates the Cap GLX-1 gene expression, but under PEG treatment has no significant change. ABA is reported to cause a general decrease in transcription.

### **Express Sequence Tag (EST) Analysis-A Useful Tool for Drought Tolerance Mechanism**

To identify the water stress induced gene, two non-normalized cDNA libraries were constructed from the seedling leaves of a drought tolerant chickpea cultivar under PEG treated and non- treated conditions. About 2500 clones from each library were selected randomly for sequence analysis. Based on IDEG 6 online software analysis, 92 genes were differentially expressed, and these genes were involved in diverse biological progresses, such as metabolism, transcription, signal transduction, protein synthesis and others. Most of the up-regulated genes were related to drought tolerance and the down regulated genes were mainly involved in photosynthesis. The differential expression patterns of five functional uni-genes were confirmed by quantitative real time PCR (qPCR) (Gao *et al.*, 2008).

To validate the EST analysis, 5 genes with different expression patterns under dehydration stress were selected for qPCR analysis (5 A-E). Among them, 3 genes, Cap LEA-1, dehydrin 1, and LTP which play important roles in drought tolerance, were found to be up-regulated under drought stress. The other 2 genes, i. e., for chlorophyll a/b binding protein and RuBISCO small subunit; that is important in photosynthesis, were down regulated under drought stress. The gene expression of Cap LEA-1 and LTP are reported to increase gradually and reach to culmination at 48 hours after PEG stress. The gene expression level of dehydrin 1 is reported to reach culmination at 12 hour after PEG stress, and then it decreased. Instead, RuBISCO small subunit is reported to be a PEG repressive gene. Its expression level decreases after PEG stress. However, after PEG treatment, the gene expression level of chlorophyll a/b binding protein slightly decreases from 0 to 24 hour, increases significantly at 36 hour, and then rapidly decreases.

### **Role of Antioxidants in Drought Stress**

In tropical countries, abiotic stresses such as water deficit often limit crop productivity. Under drought there is an enhanced generation of



reactive oxygen species (ROS), which lead to oxidative stress at the cellular level. Excess ROS is produced primarily by photosynthetic and mitochondrial electron transport systems. A major component of these defense mechanisms is the ascorbate-glutathione cycle by which ROS are detoxified. Most of the ascorbate-glutathione cycle enzymatic activities, including that of GR (glutathione reductase), are located in chloroplasts, cytosol, mitochondria and peroxisomes. However, only two forms of GR genes have been identified to date, a cytosolic isoform (cGR), and an isoform dual targeted (dtGR) to both chloroplasts and mitochondria protective mechanisms. Further, induction levels of these have been reported to vary between drought tolerant and susceptible plants. In maize, antioxidant molecules accumulate in the tolerant cultivars, but not in susceptible ones. Such observations have also been recorded in the case for ascorbate peroxidase (APX) and GR isoforms in two cowpea cultivars differing in their tolerance to drought. The cDNAs of GR encoding leaf cytosolic and dual targeted isoforms were isolated from drought tolerant and drought susceptible cultivars of *Phaseolus vulgaris*. Cowpea and Bean plants were subjected to moderate water stress followed by re-watering. Accumulation patterns of GR transcripts were analyzed in relation with their respective tolerance to drought. In drought tolerant and susceptible cultivars, IPA and Carioca, respectively, of *Phaseolus*, total GR-soluble specific activity increased in tolerant cv. IPA, but decreased in susceptible cv. Carioca under mild drought stress. In rehydrated plants (48 h), total soluble GR activity was higher than that observed in response to drought stress. In the susceptible cultivar, the activity remained lower than that of control plants (Franklin *et al.*, 2008).

Gene expression pattern of glutathione has been investigated in leaves of *Phaseolus* and *Vigna* cultivars. PvdtGR gene expression is found to be always very low compared to that of PcvGR. To detect PvdtGR PCR products, number of PCR cycles increased to 35 instead of 30 for cGR and it is reported that under moderate water stress, susceptible cultivars 1183 and Carioca showed an increase in expression of cGR and a decrease in dual targeted isoform expression, compared with control plants. In the resistant common bean cv. IPA, an increase in expression level of both genes was observed. In tolerant cowpea cultivar EPACE, transient mRNA accumulation of both GR isoforms did not change by mild drought (Franklin *et al.*, 2008).

Two genes *e1f-1* and *Ppd* have been identified for early flowering and maturity to escape drought stress in genotype ICCV-2 of chickpea under Southern Indian condition. A unique short duration chickpea variety ICPL-87 has also been developed by ICAR-ICRISAT collaboration.

### Heat Tolerance and Heat Shock Protein Genes

Increased transcription of a set of genes in response to heat or other toxic agent exposure is a highly conserved biological response, occurring



in all organisms (Waters *et al.*, 1996). The response is mediated by heat shock transcription factor (HSF) which is present in a monomeric, non-DNA binding form in unstressed cells, and is activated by stress to a trimeric form which can bind to promoters of heat shock genes. The induction of genes encoding heat shock proteins (Hsps) is one of the most prominent responses observed at the molecular level of organisms exposed to high temperature (Kimpel and Key, 1985; Lindquist, 1986; Vierling, 1991).

Genetic engineering for increased thermo tolerance by enhancing heat shock protein synthesis in plants has been achieved in a number of plant species (Malik *et al.*, 1999; Li *et al.*, 2003; Katiyar-Agarwal *et al.*, 2003). There are reports indicating a positive correlation between the levels of heat shock proteins and stress tolerance in plants (Sun *et al.*, 2001; Wang *et al.*, 2005). Although the precise mechanism by which these heat shock proteins confer stress tolerance is not known. However, it has been demonstrated that *in vivo* function of thermoprotection of small heat shock proteins is achieved via their assembly into functional heat shock granules (HSGs) (Miroshnichenko *et al.*, 2005).

### Osmotic Adjustment under Drought

It is reported that osmotic adjustment has no direct positive effect on yield under water stress (Serraj and Sinclair, 2002), but it has important role in enhancing the ability of plants to maintain root growth under severe stress (Voetberg and Sharp, 1991). Turner *et al.* (2007) also has observed no beneficial effect of osmotic adjustment on yield under drought stress in chickpea. The results of simulation model suggested that changes in the metabolic process may end up with little benefit on actual yield under stress (Passioura, 1977; 2007; Sinclair *et al.*, 2004). For agricultural purposes, over synthesis of compatible solutes should not account at the cost of primary metabolic processes (Garg *et al.*, 2002).

### SALINITY STRESS

Genes involved in stress signal sensing and cascade of stress signaling in *Arabidopsis thaliana* has been of recent research interest. Components of the same signal transduction pathway considered to be shared by various stress factors such as drought, salt and cold (Shinozaki and Yamaguchi-Shinozaki, 1999). There are multiple pathways of signal transduction system operating at the cellular level. Abiotic stress signaling in plants involves receptor coupled phosphorelation, phosphoinositol-induced  $\text{Ca}^{2+}$  changes, mitogen activated protein kinase (MAPK) cascade, and transcriptional activity of stress response genes (Xiong and Zhu, 2001). A number of signaling components are reported to be associated with the plant response to high temperature, freezing, drought and anaerobic stress (Grover *et al.*, 2001).

Vadez *et al.* (2007) reported that salinity tolerance is not related to differences in the accumulation of  $\text{Na}^+$  in chickpea. Similar data have been observed in sorghum and millet. The plant tolerance to stress is evaluated based on the seed yield under salinity stress rather than the shoot mass because there is no correlation between the shoot mass and seed yield under salinity (Vadez *et al.*, 2007). It is likely that reproduction is the key physiological process affected by salinity. Therefore, transgenic research intended to improve salt tolerance should probably be focused on those processes that appears to be sensitive to salinity stress (Pooja Bhatnagar-Mathur *et al.*, 2008).

### TRANSGENIC IN PULSES

Most of the pulses have been shown to be amenable to genetic transformation using recombinant DNA and tissue culture procedures. However, a highly reproducible transformation and regeneration system is prerequisite for the introduction of foreign gene into desired background. Effective protocols are available for regeneration via organogenesis and somatic embryogenesis in pigeonpea and chickpea. Successful efforts have been made to obtain multiple shoots through direct and indirect organogenesis. Several explants like, embryonic axes, cotyledonary node and apical shoot meristems have been tested. For development of transgenic, both *Agrobacterium* mediated and direct gene transfer methods have been used. So far, most of the transformations in pulse crops are limited to transfer of marker genes. Efforts are on to develop transgenic plants of chickpea and pigeonpea, which are resistant to gram pod borer (*Helicoverpa armigera*) using Bt crystal protein genes. At IIPR, Kanpur, transformed callus and plantlets of chickpea and pigeonpea possessing *npt II* (an antibiotic resistance), *bar* (bialaphos resistance) and *Cry IAb* genes have been obtained through *Agrobacterium* mediated transformation. Similarly, transformed plantlets have been obtained in pigeonpea using gene gun and *Agrobacterium* methods. Transformed chickpea plants possessing *Cry IAb* gene have also been reported from IARI, New Delhi, and ICRISAT, Patancheru, Hyderabad. The NCL, Pune, and NBRI, Lucknow, are also conducting research in the similar direction. Besides use of Bt genes, genes of plant origin like, lections, protease and amylase inhibitors are also of much significance. Plant chitinases with antifungal activity against several fungal pathogens have been purified. The potential of chitinases in bio-control of gram pod borer has stimulated interest to isolate genes encoding these enzymes and for cloning them into plants. The NCL Pune has an elaborate program on identification of novel plant genes conferring resistance against insect pests. Some of transgenic plants with genes for insect resistance are expected to be available commercially within few years.



## Pyramiding of Resistance Genes

Characterization of the race structure of major fungal pathogens chiefly *Fusarium* wilt, and development of gene deployment strategies to extend genetic resistance to it, is immediately required to combat highly variable pathogens. Breeding for wilt resistance in chickpea and pigeonpea requires an understanding of the contemporary pathogen populations in the locations where resistance genes are to be deployed. *Fusarium oxysporum* f. sp. *ciceri* is well known for its pathogenic diversity in the country that can render a wilt resistant cultivar resistant in one location and susceptible in another location. Based on the extensive research on the variability present in *Fusarium oxysporum* f. sp. *ciceri* in India, four races namely, race 1, race 2, race 3 and race 4 are identified out of seven reported on the global basis. The other three races are 0, 5 and 6 which are confined to Spain and California (USA). Nine race specific recessive genes have been identified for *Fusarium* wilt in chickpea. These genes are *foc-0*, *h1*, *h2*, *h3*, *a*, *b*, *c*, *foc-4*, *foc-5*, and are independently inherited, except for allelic pairs. Similarly, enough genetic variability and sufficient lines that are resistant to different races of *Fusarium udum* are available in pigeonpea, but none of the lines have resistance to most/all of the races. Traditional way of transferring one or more resistance genes to a single cultivar relies on field and green-house screening against different races, which is very laborious and time consuming. With conventional approach, breeding lines with a single dominant resistance gene cannot be distinguished from breeding lines with multiple resistance genes. However, if DNA markers are available for each resistance gene, the identification of plants with multiple genes would be easy. In recent years, DNA markers have shown great promise in lessening the time and expense for pyramiding resistance genes.

So far 354 markers are reported in chickpea, out of which three to four are reported to be closely linked with genes imparting resistance to race 1, race 4 and race 5 of *Fusarium* wilt. Besides mapping and identifying host plant resistance, efforts are being made to characterize pathogen populations making it feasible to deploy the relevant genes conferring resistance to match the pathogen population. The ability to use marker assisted selection to pyramid genes will make this technology an essential tool for pulse breeders in the present century.

## REFERENCES

- Basu, P. S. and Singh, D. N. 2003. Physiology and abiotic stresses in chickpea. In: *Chickpea Research in India*. Ali M., Shivkumar and Singh N. B., (Eds). IIPR, Kanpur, pp. 137-66.
- Burke, E. J.; Brown, S. J. and Christidis, N. 2006. Modelling the recent evolution of global drought and projections for the 21<sup>st</sup> century with the Hedley Centre climate model. *J. Hydrometeorol.* 7: 1113-15.
- FAO. 2004. *FAO production year book*, FAO, Rome.

Franklin, M. L. T.; Arbel, D. C.; Fordil, Y. Z. and Pham-Thi, A. T. 2008. Molecular cloning of glutathione reductase cDNA and analysis of GR gene expression in cowpea and common bean leaves during recovery from moderate drought stress. *J. Plant Physiol.* **165**: 514-21.

Gao, W. R.; Wang, X. S.; Liu, Q. Y.; Peng, H.; Chen, C.; Li, J. G.; Zhang, J. S.; Hu, S. N. and Ma, H. 2008. Comparative analysis of EST<sup>s</sup> in response to drought stress in chickpea. (*C. arietinum* L.). *Biochem. Res. Commu.* **376**: 578-83.

Garg, A. K.; Kim, J. K.; Owens, T. G.; Ranwala, A. P.; Choi, Y. C.; Kochian, L. V. and Wu, R. J. 2002. Trehalose accumulation in rice plant confers high tolerance levels of different abiotic stresses. *Proc. Nat. Acad. Sci. USA.* **99**: 15898-15903.

Gaur, P. M.; Krishnamurthy, L. and Kashiwagi, J. 2008. Improving drought avoidance root traits in chickpea (*Cicer arietinum* L.); current status of research at ICRISAT. *Plant Prod. Sci.* **11**: 3-11.

Grover, A.; Kapoor, A.; Satyalakshmi, O.; Agarwal, S.; Sahi, C.; Katiyar-Agarwal, S.; Agarwal, M. and Dubey, H. 2001. Understanding molecular approaches of the abiotic stress responses. *Curr. Sci.* **80**: 206-16.

Jayshree, B.; Crouch, J. H.; Buhariwala, H. K. and Shinde, Sanjeev. 2005. A legume genomics resources the chickpea not expressed sequence tag database. *Electronic J. Biotech.* ISSN: 0717-3458

Kashiwagi, J.; Krishnamurthy, L.; Serraj, R.; Crouch, J. H. and Panwar, J. D. S. 2007. Rapid and reliable screening technique for root traits in chickpea. *J. Food Legumes.* **20**: 67-70.

Kashiwagi, J.; Krishnamurthy, L.; Upadhyaya, H. D., Krishna, H.; Chandra, S.; Vadez, V. and Serraj, S. 2005. Genetic variability of drought-avoidance root traits in the mini-core germplasm collection of chickpea (*Cicer arietinum* L.). *Euphytica.* **146**: 213-222.

Katiyar-Agarwal, S.; Agarwal, M. and Grover, A. 2003. Heat tolerance in basmati rice is engineered by over expression of Hsp 101. *Plant Mol. Biol.* **51**: 677-86.

Khan, H. R.; Link, W.; Hocking, T. J. and Stoddart, F. L. 2007. Evaluation of physiological traits for improving drought tolerance in faba beans (*Vicia faba* L.). *Plant Soil.* **292**: 205-17.

Kimbel, J. A. and Key, J. L. 1985. Heat shocks in plants. *Trend Biochem. Sci.* **10**: 353-57.

Li, H. Y.; Chang, C. S.; Lu, L. S. ; Liu, C. A. ; Chang, M. T. and Chang, Y. Y. 2003. Over expression of *Arabidopsis thaliana* heat shock factor gene (At Hs fAb) enhances chilling tolerance in transgenic tomato. *Bot. Bull. Acad. Sin.* **44**:129-40.

Lindquist, S. 1986. The heat shock response. *Ann. Rev. Biochem.* **55**: 1151-91.



- Malik, M. K.; Solvin, J. P.; Hwang, C. H. and Zimmerman, J. L. 1999. Modified expression of a carrot small heat shock protein gene. *Plant J.* **20**: 89-99.
- Miroshnichenko, S.; Tripp, J.; Nieden, U. Z.; Neumann, D.; Conrad, U. and Manteuffel, R. 2005. Immunomodulation of function of small heat shock proteins prevents their assembly into heat stress granules and results in cell death at sublethal temperatures. *Plant J.* **41**: 269-81.
- Panwar, J. D. S. 2003. Drought tolerance in chickpea: Physiological approaches. *In: Drought management strategies for pulse crops*. Ali M., (Ed.). Proceedings of ICAR Sponsored Summer School at IIPR, Kanpur, pp. 72-83.
- Passioura, J. 1977. Physiology of grain yield in wheat grown on stored water. *Australian J. Plant Physiol.* **3**: 559-65.
- Passioura, J. 2007. Drought environment: Physiological, biological and agricultural perspectives. *J. Exp. Bot.* **58**: 113-17.
- Pooja Bhatnagar-Mathur, Vadez, V. and Sharma, K. K. 2008. Transgenic approaches for the abiotic stress tolerance in plants: Retrospect and prospects. *Plant Cell Rep.* **27**: 411-24.
- Romo, S.; Labrador, E. and Dopico, B. 2001. Water stress regulated gene expression in *Cicer arietinum* seedlings and plant. *Plant Physiol. Biochem.* **39**: 1017-26.
- Serraj, R. and Sinclair, T. R. 2002. Osmolyte accumulation: Can it really help increase crop under drought conditions? *Plant Cell Environ.* **25**: 333-41.
- Shinozaki, K. and Yamaguchi-Shinozaki, K. 1999. Molecular responses of drought stress. *In: Molecular Response to Cold, Drought, Heat and Salt Tolerance in Higher Plants*. Shinozaki K. and Yamaguchi-Shinozaki K., (Eds). R. G. Lands Co., Australia. pp. 11-28.
- Sinclair, B. J.; Jaco Klok, C. and Chown, S. L. 2004. Metabolism of the suantartic caterpillar *Pringlesphaga marioni* during cooling, freezing and thawing. *J. Exp. Biol.* **207**: 1287-94.
- Sun, W.; Bernard, C.; Van de Cotte B.; Montague, M. V. and Verbruggen, N. 2001. At-HSPA-6A encoding a small heat shock protein in *Arabidopsis*, can enhance osmotolerance upon over expression. *Plant J.* **27**: 407-15.
- Turner, N. C.; Shahal, A.; Berger, J. D.; Chaturvedi, S. K.; French, R. J.; Ludurg, C.; Mannur, D. M.; Singh, S. J. and Yadava, H. S. 2007. Osmotic adjustment in chickpea (*Cicer arietinum* L.) results in no yield benefit under terminal drought. *J. Exp. Bot.* **58**: 187-94.
- Vadez, V.; Krishnamurthy, L.; Gaur, P. M.; Upadhyay, H. D.; Hosistington, Varshney, R. K.; Turner, N. C. and Sidique, K. H. M. 2007. Large variation in salinity tolerance is explained by differences in the sensitivity of reproductive stage in chickpea. *Field Crop Res.* **104**: 123-29.

Vadez, V.; Krishnamurthy, L.; Gaur, P. M.; Upadhyay, H. D.; Hosistington, Varshney, R. K.; Turner, N. C. and Sidique, K. H. M. 2006. Taping the large genetic variability for salinity tolerance in chickpea. *Proc. Australian Soc. Agron. Meeting*, 10-14 Sept. 2006.

Vierling, E. 1991. Role of heat shock proteins in plants. *Ann. Rev. Plant Physiol. Plant Mol. Biol.* **42**: 579-620.

Voetberg, G. S. and Sharp, R. E. 1991. Growth of the maize primary root tips at low water potential III. Role of increased proline deposition in osmotic adjustment. *Plant Physiol.* **96**: 1125-30.

Wang, Y.; Ying, J.; Kuzma, M.; Chalifoux, M.; Sample, A.; Mc Arthur, C.; Uchacz, T.; Sarvas, C.; Wan, J. and Denis, D. T. 2005. Molecular tailoring of farnesylation for plant drought tolerance and yield protection. *Plant J.* **43**: 413-26.

Waters, E. R.; Lee, C. J. and Vierling, E. 1996. Evolution, structure and function of the small heat shock proteins in plants. *J. Exp. Bot.* **47**: 325-38.

Xiong, L. and Zhu, J. K. 2001. Plant abiotic stress signal transduction: molecular and genetic perspective. *Physiol. Plant.* **112**: 152-66.



## **CHAPTER 15**

# **Effect of Greenhouse Gases and Global Warming on Pulses**

**S**ince the dawn of civilization, human activities have always made significant impact upon the environment. Now the biosphere is facing a serious crisis because of drastic environmental changes. The global climatic change may irreversibly alter the environmental conditions, which may be most detrimental to biodiversity in general and human civilization in particular.

A fraction of incoming solar radiation acts to heat up the earth's surface. Some portion of the incoming solar radiation is reflected back into the space by the earth's atmosphere, a fraction of it is dispersed and scattered by the particles in the atmosphere, while a large proportion of it penetrates atmosphere and reaches to the surface of the earth. Radiations reaching the surface of earth are largely absorbed, resulting in surface warming. Much of this absorbed energy is re-radiated outwards in the form of longer wavelength thermal radiations, i.e. infra rays (IR). Some of these radiations escape out to space, but a large portion is absorbed by the earth's atmosphere.

Gases that play significant role in absorbing the heat radiations in the atmosphere are called as greenhouse gases (GHGs). Water vapour, carbons dioxide, methane, and nitrous oxide, etc. trap heat radiations. Carbon-di-oxide, methane, and nitrous oxide, therefore, are termed as green house gases. CO<sub>2</sub> and other green house gases make a thick blanket in the atmosphere and traps more thermal (infra red) radiations. This help in warming up of the earth. Industrialization, deforestation, increased use of fossil fuels and changes in land use pattern are contributing significantly in increasing the concentration of green house gases in the atmosphere, resulting in increased global temperature at an exponential rate. Greenhouse gases have registered a considerable change during the past 100 years. The methane level has increased from the pre-industrial values of about 715 ppb (parts per billion) to 1174 ppb in 2005, nitrous oxides concentration has increased from 270 ppb to 319 ppb and CO<sub>2</sub> concentration has changed from 280 ppm to 390 ppm in the same period. It is expected that in days to come the concentration of these gases will change with a much higher rates, if preventive measures are not followed.

The CO<sub>2</sub> concentration in atmosphere is projected to reach to 405 to 460 ppm by 2025, 445 to 640 ppm by 2050, and 720 to 1020 ppm by

2100 AD. The projected global mean temperature for these CO<sub>2</sub> stabilization scenarios are 0.4-1.1°C by 2025, 0.8-2.6°C by 2050, and 1.4 to 5.8°C by 2100, above the global mean temperature that prevailed in 1990 AD. The projected mean sea level rise for those periods are expected to be 3 to 14, 5 to 32 and 9 to 88 cm, respectively (Raja Reddy and Kakani, 2008).

In addition to the above agents, the black carbon and ozone gas are very important pollutants of concern. The black carbon is a wide spread form of particulate air pollution. The black carbon alters the environment in two ways: (i) in the atmosphere the suspended particles absorb sunlight, and (ii) deposits of black carbon on snow packs and other objects on earth soil surface absorb sunlight and cause increase in temperature of objects and melting of glaciers. The warming effect of black carbon is about 20-50% of the effect of CO<sub>2</sub> and; therefore, contributes significantly to global warming (Wallack and Ramanathan, 2009).

India is predominantly an agrarian economy as 52% of the population directly dependent on agriculture. Most of them are farmers, and about 76% of them reside in the villages. Climatic change, therefore, will have a direct impact on the livelihood of these people. The impact of climatic change can roughly be divided into two groups:

- (i) **Biophysical Impact:** The climate change would cause physiological effects on crops, pasture, forest and livestock (quality and quantity). It will result in changes in land, soil and water resources, increase in weed and insect-pest challenges, sea level rise, changes in ocean salinity, and increase in sea temperature causing fishes and other marine organisms to inhabit different ranges.
- (ii) **Socio-economic Impact:** Socio-economic impact of global climate change would be in terms of decline in crop yields and production, reduced marginal GDP from agriculture, and fluctuations in world market prices. It would also cause change in geographical distribution of trade regimes, increased risk of hunger and food insecurity, population migration, and civil unrest.

Increase in temperature, change in precipitation pattern (quantity and distribution), and an increase in extreme weather events are likely to change food production potential in many area of the world, especially in tropical and sub-tropical regions of the world.

The global agricultural production potential is likely to rise with increase in global average temperature up to about 3°C, but above this it is very likely that production potential may decrease. Part of the world with cold climate (temperate regions) would be benefited from increased global temperatures as new agricultural land may become available at higher latitude and high elevations. On the contrary, places at lower latitude, especially the seasonally dry tropics, crop yield potential is likely to decrease even with a small global temperature increases, and this would



increase risk of hunger. Increased frequency of drought and floods would affect local production negatively, especially in subsistence sectors at low latitude. Global climate change will have much more serious consequences for chronic and transitory food insecurity and for sustainable development.

### Effect of Global Warming on Pulses in India

With the 25% share in the global pulse production, India is the largest producer of pulses in the world. The important pulse crops like chickpea, pigeonpea, mungbean, urd bean, lentil, field peas are contributing 39%, 21%, 11%, 10%, 7% and 5% of the total pulse production of the country.

All pulses are  $C_3$ -plants. Increase in atmospheric carbon-di-oxide concentration; therefore, is expected to have a positive effect on pulse productivity because it will result in reduction in photorespiration and increase in net photosynthesis, reduction in the water loss by plants, and increased water-use-efficiency. It is possible as long as no other factors such as water, nutrients and heat stress are limiting the crop growth and development. In all  $C_3$  plants, including pulses, net photosynthesis is limited at current level of  $CO_2$ . Rising atmospheric  $CO_2$  concentration will reduce this limitation. Increased atmospheric  $CO_2$  level will enhance the rate of photosynthesis by increasing rate of carboxylation reaction of RuBISCO and decreasing the oxygenation reaction of photorespiration. Such effects have been observed in mungbean and barseem (Madan Pal *et al.*, 2008).

Atmospheric  $CO_2$  concentration at its present level of 390 ppm limits the photosynthesis rate in  $C_3$  plants. This is because RuBISCO, which catalyses the entry of  $CO_2$  into photosynthetic metabolism has low affinity to  $CO_2$ . For present day terrestrial  $C_3$  species the  $K_m$  value (the substrate concentration at which rate of reaction is half of the maximum) of RuBISCO for  $CO_2$  is 10-25  $\mu M$ , where as chloroplast stroma (site of carboxylation in photosynthesis) of  $C_3$  plants contains only about 5  $\mu M$   $CO_2$  (Bowes, 1993). A rise in atmospheric  $CO_2$  concentration, therefore, is aught to reduce this limitation by increasing  $CO_2$  concentration at the site of carboxylation. Carboxylation efficiency in  $C_3$  plants will further be stimulated as  $CO_2$  competes with  $O_2$  at the active site of RuBISCO and decreases oxygenation, consequently the photorespiration (Liang *et al.*, 1974; Ogren, 1984; Kimbell *et al.*, 1993). In soybean, carbon exchange rate is reported to increase up to an elevated  $CO_2$  concentration of 990  $\mu mol mol^{-1}$  (Jone *et al.*, 1984). Increase in ambient  $CO_2$  level also results in increased yield in this crop (Jone *et al.*, 1984). In rice, a  $C_3$  cereal, the carbon exchange rate is reported to increase with increase in  $CO_2$  concentration up to 500  $\mu mol mol^{-1}$ , but levels off at higher  $CO_2$  values. Photosynthetic response under elevated  $CO_2$  environment is reported not to be consistent and decreases after a period of few days or weeks (Sage *et al.*, 1989).

During *rabi* season, dew is a common phenomenon and it is quite

useful for the crops growing under rainfed condition. With increased global temperature, the phenomenon of dew precipitation will diminish and; therefore, crops will be subjected to too much dry weather and high evapotranspiration. Under such situation crop will suffer from drought and heat stresses. Crop yield will be affected more due to severe terminal heat stress. At present there is a shift in pulse crops production and productivity from northern part to the central and southern parts of the country. One of the reasons for such shift is supposed to be the existence of favorable temperature and rainfall, and presence of black soil that has higher water holding capacity that supports grain development during maturity period in the central and southern parts of the country. At present the area under pulse crops in southern part of India has almost doubled as compared to that which was in 1971-75, where as in the same period it has reduced to about 50% in northern part. In Northern India the abrupt rise and fall in atmospheric temperatures has been observed in the last decade. As a result of this the duration of winter season has shortened, which has resulted in increase in flower/pod drop and poor seed set with small and shriveled grain, leading to poor grain yield.

In North India during *rabi* season, it has been noticed that duration and intensity of foggy weather condition is increasing, particularly during December end to mid February. During this period the atmospheric humidity increases tremendously, and the intensity of light reaches below the compensation point. As a result, the photosynthetic rate declines and availability of assimilates during reproductive period of the *rabi* pulses decreases, resulting in poor seed setting and seed development. The bursting of anthers may also be affected causing poor fertilization and hence poor seed set. This type of data is lacking in literature and there is a need to work on these aspects in future too.

## REFERENCES

- Bowes, G. 1993. Facing the inevitable: Plants and increasing atmospheric CO<sub>2</sub>. *Ann Rev. Plant Physiol. Plant Mol. Biol.* **44**: 309-32.
- Jone, P.; Allen, L. H. Jr.; Jones, J. W.; Boote, K. J. and Campbel, W. J. 1984. Soybean canopy growth, photosynthesis and transpiration response to whole season carbon di oxide enrichment. *Agron. J.* **76**: 633.
- Kimbell, B. A.; Mauney, J. R.; Nakayama, F. S. and Idso, S. B. 1993. Effects of increasing atmospheric CO<sub>2</sub> on vegetation. *Vegetatio*. **104 /105**: 65.
- Liang, W. A.; Ogren, W. L.; Hageman, R. H. 1974. Regulation of soybean net photosynthetic CO<sub>2</sub> fixation by the interaction of CO<sub>2</sub>, O<sub>2</sub>, and ribulose 1-5 di phosphate carboxylase. *Plant Physiol.* **54**: 678.
- Madan Pal, Talwar, S.; Deshmukh, P. S.; Vishwanathan, C. and Khetrapal, S. 2008. Growth and yield of chickpea under elevated carbon di oxide concentration. *Indian J. Plant Physiol.* **10**: 25-31.



Ogren, W. L. 1984. Photorespiration: Pathways, regulation and modification. *Ann. Rev. Plant Physiol.* **35**: 415.

Raja Reddy, K. and Kakani, 2008. Screening for genotypic variability among crops to global environmental changes: Challenges and opportunities. *Proceedings of the Golden Jubilee Conference on Challenges and Emerging Strategies for Improving Plant Productivity*, Indian Society Plant Physiol. and IARI, New Delhi, India during. 2008, pp. 21-23.

Sage, R. F.; Sharkey, T. D. and Seeman, J. R. 1989. Acclimation of photosynthesis to elevated  $\text{CO}_2$  in five  $\text{C}_3$  species. *Plant Physiol.* **89**: 590.

Wallack, J. S. and Ramanathan, V. 2009. The other climate changers: Why black carbon and ozone also matter. *Foreign Affairs.* **88** (5): [http://www.projectsurvey.org/storage/WallackRam\\_FApp105-2009.pdf](http://www.projectsurvey.org/storage/WallackRam_FApp105-2009.pdf) ●







## About the Book

This book consists of 15 chapters on production and productivity scenario, canopy and root development, biological nitrogen fixation, physiology of growth and yield components, light and water-use efficiency, physiological aspects of pulse-cereal intercropping and nutritional qualities concerned with all major and minor pulses, viz. chickpea, pigeonpea, MULLaRP, and arid legumes (cowpea, moth bean, *guar*, winged bean), grown in different agro-ecological regions of India.

A brief botany, origin and economic uses have also been covered. Chapters on ideal plant type as well as molecular basis and effect of greenhouse gases and global warming in pulses have been included in this book.

The book will fulfill the growing needs of all students and researchers of agricultural sciences in general, particularly of crop physiology.

